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A FRAMEWORK FOR ANALYSIS OF THE WEAPONS IMPLICATIONS OF THE U.S.-INDIA NUCLEAR ACCORD

Paul Nelson, Taraknath V. K. Woddi and
William S. Charlton

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EXECUTIVE SUMMARY

India's options are analyzed, in terms of the feasible region available in "uranium-policy space" (amounts of indigenous uranium employed to produce each of weapons-grade and reactor-grade plutonium). This approach is employed to evaluate, via several different metrics, the "immediate future" impact of the proposed cooperation, relative to the status quo, and to other "baseline scenarios." Conclusions are that the cooperation benefits nuclear power production in India, while assessments of its potential contribution to proliferation depend sensitively on choice of metric, baseline scenario, and hypothesis regarding production of indigenous uranium. A sufficiently large increase in the historic rate of production of indigenous uranium could lead to an "excess," relative to needs for energy production, which could be used for weapons; however, under the status quo India could accomplish much the same, by decommissioning its older reactors. Relative to several metrics of the potential for vertical proliferation, the cooperation is shown to have rather marginal impact, as compared to the situation at the time of the initial Joint Statement envisioning the cooperation.

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I. INTRODUCTION

In the advent of the proposed U.S.-India civil nuclear cooperation agreement,[1] conflicting propositions have appeared regarding the possible flow of fissile materials in India. One of these is the simple and intuitively appealing argument that:

> **Proposition I:** "Foreign nuclear fuel supplies would free up India's limited domestic nuclear fuel making capacity to produce highly enriched uranium and plutonium for weapons."[2]

The alternative proposition, which perhaps is equally simple and intuitive, yet leads to a diametrically opposed conclusion, is as follows:

> **Proposition II:** Under either the proposed cooperation or the ongoing status quo, India will have the ability to transform all its indigenous uranium into one of the three weapons-usable forms, highly enriched uranium, weapons-grade plutonium or reactor-grade plutonium. The proposed cooperation reduces in perpetuity the reactor capacity India has available to produce the latter two forms, and therefore serves only to further limit its capability to produce nuclear weapons.

Among the conclusions of Mian, Nayar, Rajaraman and Ramana,[3] hereafter referred to as "MNRR," there appears: "India may be able to divert the additional 70-120 tons/year (of uranium, beyond that needed to fuel its strategically reserved thermal power reactors for electrical production) toward producing 60-100 kg/year of weapons grade plutonium."[4] (Parenthetical clarification added.) This conclusion seems to support Proposition I above, and associated concerns that the proposed cooperation could lead to a rapid expansion of India's nuclear arsenal, as opposed to its traditional "moderate pace."[5]

The purpose of this note is to present a general framework for discussing these matters that we believe can serve to help in understanding the source of such radically different conclusions. The intention of such a framework is to provide a sharper focus upon the assumptions underlying any high-level propositions, such as those above.

The remainder of this note is divided into five sections: Uranium-policy diagrams, metrics, selection of uranium strategies, alternative baseline scenarios, and conclusions.

II. URANIUM-POLICY DIAGRAMS

The proposed framework is based on a broad view of the options available to India in using its indigenous supplies of uranium. The principal tool for illustrating these options is a *uranium-policy diagram*. The example diagram in Figure 1 is for a scenario of the immediate future,[6] with the proposed cooperation. The solid line represents the constraint imposed by the available amount of indigenous Indian uranium, taken here as 475 tonnes per year. The dotted line represents the "strategic-capacity constraint," which is to say the curve of maximum possible throughput of uranium in the reactors that have not been declared as civil, in due consideration of the rate at which these reactors can achieve the required burnup.[7] The rightmost vertical segment of the strategic-capacity constraint represents an effort to take refueling-rate and excess-reactivity considerations, as discussed by Tellis,[8] into account by assuming their net effect is to restrict no more than ¼ of the fuel in core to be devoted to production of weapons-grade plutonium, at the 80% capacity factor used for Figure 1.[9] (The significance of the various labeled points is discussed below.) For brevity, the scenario underlying Figure 1 will be termed the "IFPC-475 scenario."

The corresponding uranium-policy diagram for the "IFSQ-475" scenario of the immediate future and the status quo (no cooperation) is shown in Figure 2.[10] For both of these two scenarios the feasible region of uranium-policy space is the lightly shaded region of policy space that lies below both the strategic-

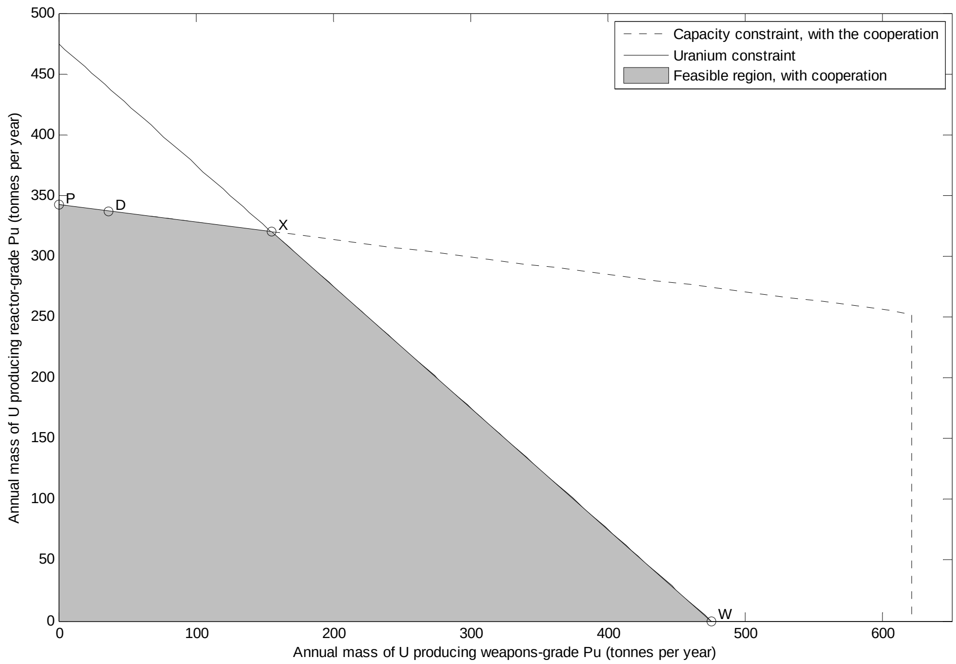

Figure 1 – Uranium-policy diagram for Scenario IFPC-475.

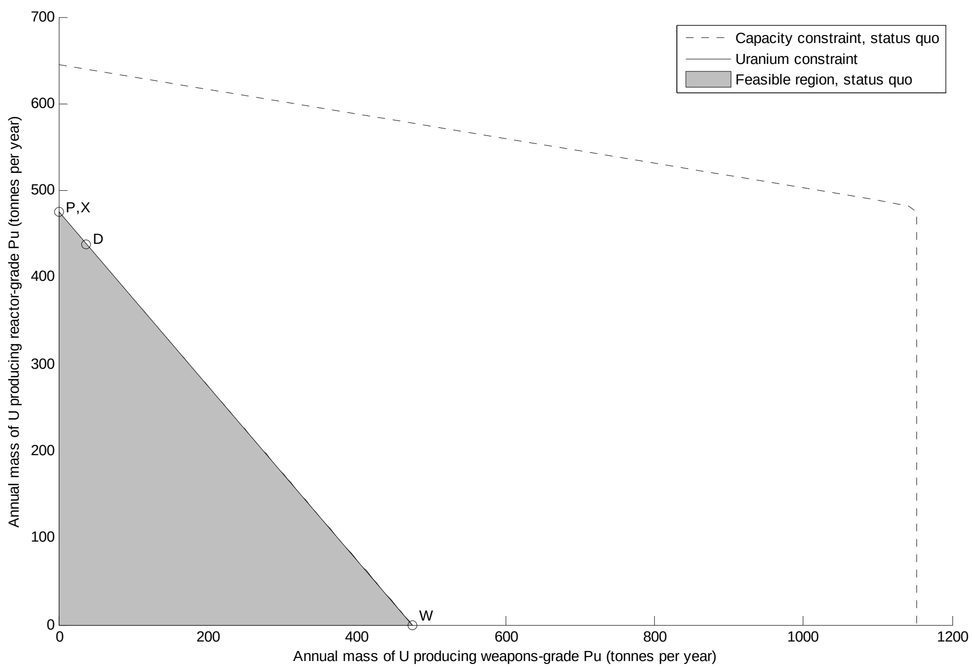

Figure 2 – Uranium-policy diagram for Scenario IFSQ-475.

capacity constraint and the uranium constraint. For the IFPC-475 scenario this is the quadrilateral at the lower left, because the strategic-capacity constraint is most binding at the far left (small production of weapons-grade plutonium), while the uranium constraint is the operative restriction at larger production of weapons-grade plutonium. For the IFSQ-475 scenario the uranium constraint is binding at all levels of production of weapons-grade plutonium, so the shaded triangle in Figure 2 is the feasible region.

The 475 tonnes per year used as the rate of production of indigenous Indian uranium in the above scenarios is the mean of the range estimated in MNRR (p. 135). This is a significant increase over their estimate that "current uranium production within India is less than 300 tons of uranium a year."[11] There are reasons to believe the historic rates of production have been closer to 200 tonnes,[12] and there are significant issues that could adversely affect attempts to develop additional mines or improve the productivity of existing mines.[13] In order to consider sensitivity to these uncertainties, below we also consider the IFPC-300 and IFSQ-300 scenarios, in self-explanatory terminology. The corresponding uranium-policy diagrams differ, from Figures 1 and 2 respectively, only by appropriate downward shifts of the associated uranium constraints.

III. METRICS

By a *uranium strategy* is intended an ordered set of priorities for the use of indigenous uranium that, given a scenario, determines a unique *operating point,* or point within the feasible region of the corresponding uranium-policy diagram. Given a particular scenario, India is, in principle, free to select any operating point.[14] However, many of the opinions that have been expressed about the proposed cooperation appear to revolve about hopes (or fears) that it will make more likely some uranium policy that leads to an operating point having particularly (un)desirable attributes.[15] The essential idea of the analytic framework proposed here is that a suitable measure of the magnitude of the attribute associated to such an operating point provides a *metric* for assessing the relative desirability of different scenarios (e.g., IFPC-475 and IFSQ-475).

Some of these metrics, along with the corresponding strategies, operating points and attributes, are as follows. Values of these metrics, for the four scenarios mentioned above, are given in Table I.

Aggregate power capacity (APC): This metric derives from a hypothetical *power-only* strategy in which India would seek to maximize production of reactor-grade plutonium from reactors held in strategic reserve, but would not create any weapons-grade plutonium. The corresponding operating point is the intersection of the boundary of the feasible region with the vertical axis of the associated uranium-policy diagram. For the IFPC-475 and IFSQ-475 scenarios these operating points are labeled "P" in respectively Figures 1 and 2. The corresponding attribute of obvious interest is the total amount of such electrical energy production from all reactors, both civil and those reserved for possible strategic use, at this operating point. Here we denominate this metric in terms of estimated average power (MWe) production.

Latent weapons capacity (LWC): This metric derives from a hypothetical *weapons-first* strategy in which India would similarly seek to maximize its production of weapons-grade plutonium from its strategic reactors. The corresponding operating point would be the intersection of the boundary of the feasible region with the horizontal axis of the corresponding uranium-policy diagram, as illustrated by the points labeled "W" in Figures 1 and 2. The attribute of concern is production of weapons-usable material. The metric chosen to measure that attribute is kilograms per year of weapons-grade plutonium.

Excess uranium(EU): This metric is predicated on a *power-first* strategy, under which India would again seek to maximize its production of nuclear-generated electricity, but any indigenous uranium excess to that need would be employed at lower burnups, to produce weapons-grade plutonium in the strategic reactors. The corresponding operating points are at the intersection of the strategic-capacity and uranium constraints, or at the intersection of the latter and the vertical axis, in the case that the former lies entirely above the latter. Examples are the points labeled "X" in Figures 1 and 2. The attribute of concern is the capability to produce weapons under this strategy. The metric we employ here to measure that attribute is *excess uranium,* defined as the available indigenous uranium less the amount of uranium necessary to fully utilize the strategically reserved reactors to produce reactor-grade plutonium. Negative values for this metric (cf. Table I) indicate scenarios in which the estimated available amount of indigenous uranium is insufficient to fuel the strategically reserved reactors at their assumed 80% capacity factor, even at the lower burnup that produces reactor-grade plutonium.

Latent facilities capacity (LFC): This metric is also predicated on a weapons-only strategy, but now for a hypothetical scenario with unlimited uranium availability. The corresponding operating point would be at the intersection of the strategic-capacity constraint and the horizontal axis in the uranium-policy diagram. The attribute of concern is the capacity to create weapons-grade plutonium, given unlimited availability of uranium. The metric used here to measure that capacity is kilograms per year of weapons-grade plutonium that would be produced at the operating point just described.

Table I – Values of the four metrics, for the four scenarios delineated above

Scenario	Aggregate power capacity[16]	Latent weapons capacity[17]	Excess uranium	Latent facilities capacity[18]
IFPC-475	5424 MWe	428 kg WGPu/yr	133 tonnes U/yr	559 kg WGPu/yr
IFPC-300	5213 MWe	270 kg WGPu/yr	-42 tonnes U/yr	559 kg WGPu/yr
IFSQ-475	4658 MWe	428 kg WGPu/yr	-171 tonnes U/yr	1038 kg WGPu/yr
IFSQ-300	3525 MWe	270 kg WGPu/yr	-346 tonnes U/yr	1038 kg WGPu/yr

A comparison of the values of the APC metric for the IFPC-475 and IFSQ-475 scenarios suggests the proposed cooperation would enable a modest 16% increase in civil nuclear energy in India, under the more optimistic estimate of 475 tonnes per year for indigenous uranium production. For the more conservative estimate of 300 tonnes per year the corresponding increase is about 42%. While the latter is relatively significant, it is small in absolute terms. By comparison, the four reactors currently operating in Texas provide approximately 4000 MWe of electrical power, and Texas produces only about half the fraction of its electrical power from nuclear as does the U.S. as a whole.[18] In any event the immediate significance of the proposed cooperation depends considerably upon the level of production of indigenous uranium. As already discussed, future levels of production are rather uncertain. This uncertainty likely contributes to the current vigorous debate in India regarding the proposed nuclear cooperation.[19]

The LWC metric has the same values, at the same levels of production of indigenous uranium, for the PC and SQ scenarios. There is thus no disadvantage (or advantage) of the proposed cooperation, relative to this measure. Use of this metric is one way to arrive at Proposition II above. The relevance of the underlying weapons-first strategy is discussed further below. Here we simply note these latent weapons capabilities are, in absolute terms, quite significant. The value of 428 (270) kilograms of weapons-grade plutonium per year corresponds to approximately 54 (34) IAEA significant quantities[20] (eight kilograms). This large latent weapons capability emphasizes the nuclear danger currently existing in South Asia. The disparity between this latent capability and estimates that suggest India has historically produced material for 2-4 nuclear weapons annually[21] emphasize the degree of restraint exercised by India, as referenced in the opening paragraph above.

The value of the EU metric for the IFPC-475 scenario is 133 tonnes per year of indigenous uranium available to produce weapons-grade plutonium. This is slightly greater than the estimate of MNRR, as quoted in the opening paragraph of this note. It is equivalent to approximately 120 kilograms of weapons-grade plutonium, or 15 significant quantities, which would be a significant increase over consensus estimates of India's past rate of production of weapons-grade plutonium. This measure is thus consistent with the concern expressed in Proposition I above. Further discussion of the significance of the values of the EU metric in Table I is deferred until the next topic.

The values of the LFC metric are considerably smaller (by approximately half) for the cooperation scenarios than for the *status-quo* scenarios. This metric thus provides an even more emphatic route to the conclusion in Proposition II above. Nonetheless, the absolute values of this metric are alarmingly high.

IV. SELECTION OF URANIUM STRATEGIES

Suppose one accepts the more-or-less conventional wisdom that production of electricity from nuclear power, and thus of reactor-grade plutonium, is desirable, while production of weapons-grade plutonium, with the concomitant lower production of electrical energy, is undesirable. Then operating points to the upper left in a feasible region are preferable to those in the lower left. Under this criterion the preferred operating point is that in the upper left corner; e.g., those labeled "P" in Figures 1 and 2. Nonetheless India has steadfastly declined, under current circumstances,[22] to join the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) as a non-nuclear weapons State (NNWS). This would legally oblige it to follow an energy-only policy, and thus work at this preferred operating point.

Further, India has even declined to join any international agreement (e.g., a Fissile-material Cutoff Treaty) that would prevent it from operating at or near the least desirable point, at the lower right of a feasible region. There seems to be no belief that India has in fact ever followed a weapons-first policy, as would lead to this; however, India's nuclear history is consistent with a firm resolve to retain the ability and right to adopt a weapons-first policy, should circumstances evolve so that is considered necessary. This approach is quite in spirit with some interpretations of India's doctrine of "minimal credible deterrence."[23]

The history of the Indian nuclear program is consistent with a *limited weapons-first* uranium policy. The points labeled "D" in Figures 1 and 2 are instances of the operating points corresponding to such a policy. (In these cases, as instantiated by devoting the 100 MWth Dhruva reactor to production of weapons-grade plutonium, and producing only reactor-grade plutonium with all remaining indigenous uranium.) Although this operating point does not agree exactly with any of those resulting from any of the strategies previously discussed, by any accounting it is as close or closer to the preferred energy-only operating point than to that of either of the other two strategies mentioned above. In that sense the current Indian uranium strategy is more-or-less benign. The international community is therefore understandably apprehensive about the possibility of changes in its relationship with India that might result in India significantly changing its uranium strategy.

One example of such a possible change in India's uranium policy is as follows. Positive values of the excess-uranium metric measure the potential for a change in India's uranium policy that would move its operating point toward the less desirable portion of the feasible region (i.e., to points "X"), from its traditional position (at points "D"), with no concomitant cost in the form of decreased production of electrical energy. The possibility of such a policy change cannot be neglected, as it has been advocated by some within India.[24] Most expressed concerns about such a revised policy focus upon the potential for it to trigger a renewed nuclear arms race in South Asia.[25]

Certainly the potential exists for such an undesirable change. However, once one contemplates the potential for nuclear relations between India and the international community to affect India's uranium strategy, it is necessary to consider all such possibilities. Specifically, the traditional limited weapons-first policy evolved during a period that permitted most of India's indigenous pressurized heavy water reactors (PHWRs) to be fueled by domestic uranium. With the eight additional PHWRs recently completed or nearing completion, this seems unlikely to continue; corresponding scenarios are signaled by negative values of the excess-uranium metric in Table I. In such cases the magnitude of this metric measures the amount of the shortfall in fuel for those reactors to be fuelled domestically.

For the IFPC-300 scenario this shortfall is only 42 tonnes per year, or about 12% of the 342 tonnes per year required to fully fuel the strategically reserved reactors. This is probably more-or-less tolerable, without drastic changes in the uranium policy of the Indian Department of Atomic Energy (DAE). At the other extreme, for the conservative IFSQ-300 scenario the shortfall is 346 tonnes per year, which is more than 53% of the required 646 tonnes. Even the somewhat optimistic IFSQ-475 scenario displays a shortfall of 171 tonnes per year, or over 26%. Thus the shortfall is rather large for the *status-quo* scenarios.

If the proposed cooperation failed to be approved, on either the American or the Indian side, then India necessarily would be faced with the possibility of something resembling the *status-quo* scenarios. How might it react to such circumstances? Most likely its first preference would be to relax the uranium constraint, by finding additional sources, either indigenous or international (but not American). Neither of these two possibilities appears likely to involve the same degree of incentive toward nonproliferation (i.e., the upper left of the resulting feasible region) as would the proposed cooperation with the U.S.

Should it not prove feasible to relax the uranium constraint in either of these manners, then India could bring its strategic-capacity constraint into greater conformity with the uranium constraint, for example by decommissioning some of its older reactors. To some extent its readiness to do this is already signaled by the fact that its older reactors are the ones that have been declared to be civil facilities. If all of the putatively civil reactors were decommissioned, then the strategic-capacity constraint would be precisely as in Figure 1. The metrics for the corresponding scenarios, say IFSQ′-475 and IFSQ′-300, would have the same values as those of Table I, for the corresponding scenarios under the proposed cooperation, except that the values of the APC metric would be respectively 3896 MWe and 3685 MWe, because of the unavailability of the decommissioned reactors. Under these scenarios the measures of proliferation potential (or national security impact) would therefore not be affected, relative to a baseline of the corresponding scenarios under the proposed cooperation, while the measures of energy benefit would be profoundly reduced. This could provide additional incentive for India to increase its nuclear arsenal, especially should the lack of approval occur on the U.S. side.

The values of the LFC metric emphasize yet another effect of the proposed cooperation, vis-à-vis the *status quo*. This effect would occur if India should, at some time, succeed in relaxing its uranium constraint, as discussed above. The smaller values of the LFC metric for the scenarios of the proposed cooperation mean that India will have, given unlimited availability of uranium, a significantly lower capability (slightly more than half) to produce weapons-grade material than under the status quo. This is simply due to its commitment to place eight additional reactors under safeguards, in perpetuity. One can, of course, argue that there is a vanishingly small likelihood the availability of uranium to India would ever increase to the point that the strategic-capacity constraint became binding. Nonetheless, this is an extremely important symbolic concession on the part of India; it is a *de facto* limitation, via international treaty, upon its capability to produce nuclear weapons, which is something that it has never before accepted.

Table I assigns values, for each scenario discussed above, to metrics that may be figures of merit (e.g., APC) or of demerit (LWC, LFC), or that even might have some optimal value (e.g., arguably zero for EU). Yet these cannot give a complete story, because these metrics are based on hypothetical uranium strategies, none of which are likely ever to be realized in their pure form. For a complete comparison of the consequences of the proposed cooperation to those of the status quo what one would like is some probability distribution over all of the corresponding operating points.[26] That ideal is beyond the scope of the present work, and perhaps is unattainable. However, the arguments of the preceding several paragraphs provide some sense of the impact that either adoption of the proposed cooperation or maintenance of the *status quo* might have upon India's choice of uranium strategies.

V. ALTERNATIVE BASELINE SCENARIOS

The IFSQ scenarios probably provide the most useful baseline for consideration of policy decisions. Other scenarios exist that might provide useful baselines for understanding particular perspectives regarding the proposed cooperation:

The *IFNNWS scenario* is based on a hypothetical situation of an immediate future, as defined above, in which India becomes signatory to the NPT as a NNWS. Although such a scenario has little possibility of arising, because of India's national security concerns, it provides a useful benchmark for comparing the proposed cooperation against the nonproliferation ideal.

The *IFNWS scenario* is based on an equally hypothetical immediate future in which India has become a signatory to the NPT as a nuclear-weapon State. This is a useful baseline scenario for considering the occasional suggestions that the proposed cooperation is tantamount to giving status to India as a NWS under the NPT.[27]

The *JL1805 scenario* is based on the existing situation as of the date of signing of the initial Bush-Singh Joint Statement.[28] This is a useful baseline scenario for addressing both Indian perceptions of the effect of the proposed cooperation upon its national security, and issues related to the effect of the cooperation upon U.S. fidelity to that part of Article I of the NPT that requires "each nuclear-weapon State Party to the Treaty … not … in any way to assist … any non-nuclear-weapon State to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices …."

Values of the four metrics introduced above are listed in Table II, for the two IFPC scenarios previously discussed, and these three new baseline scenarios. As regards the APC metric, there is little difference across the IF scenarios, but all are considerably superior to the immediate past, as represented by the Jl1805 scenario. For the IFPC scenarios the values of the metrics that measure proliferation potential

Table II– Values of the four metrics, for the two IFPC scenarios and the three additional baseline scenarios

Scenario	Aggregate power capacity	Latent weapons capacity	Excess uranium	Latent facility capacity
IFPC-475	5424 MWe	428 kg WGPu/yr	133 tonnes U/yr	560 kg WGPu/yr
IFPC-300	5213 MWe	270 kg WGPu/yr	-42 tonnes U/yr	560 kg WGPu/yr
IFNNWS[29]	5424 MWe	0 kg WGPu/yr	0 tonnes U/yr	0 tonnes U/yr
IFNWS	5424 MWe	1018 kg WGPu/yr	∞	1038 kg WGPu/yr
Jl1805[30]	1667 MWe	270 kg WGPu/yr	-60 tonnes U/yr	536 kg WGPu/yr

(LWC,EU,LFC) are lower than for the IFNWS scenario, but mostly higher than for the IFNNWS scenario. As compared to the Jl1805 scenario, the proliferation metrics are roughly comparable for the conservative IFPC-300 scenario, and a bit larger for the optimistic IFPC-475 scenario.

VI. CONCLUSIONS:

The conclusions one draws regarding the desirability of the proposed U.S.-India nuclear cooperation in the immediate future depend sensitively upon both the metric employed and the baseline scenario used for comparison.

- In all cases the proposed cooperation is advantageous relative to the aggregate power capacity, a measure of India's capability to generate electricity from nuclear energy.

- Depending upon India's level of production of indigenous uranium in the near future, the proposed cooperation may lead either to an excess or a shortage in the uranium needed to fuel fully the power reactors retained in strategic reserve. The former poses some proliferation risk. Under the status quo (i.e., absent the cooperation) the shortage will be greatly exacerbated, which arguably poses a similar proliferation risk.
- Under the proposed cooperation, India's latent facilities capacity, a measure of its ability to produce nuclear weapons under a sufficiently large supply of indigenous uranium, would be significantly smaller than under the *status quo*.
- Under the proposed cooperation, and in the immediate future, by most measures India's capability to produce nuclear weapons will be approximately the same as it was on July 18, 2005, the date of signing of the first Bush-Singh Joint Statement.

These divergent conclusions emphasize the difficulty in analyzing, as is called for in the U.S. enabling legislation,[31] the impact of the proposed cooperation upon the Indian nuclear arsenal. In order to provide the fullest perspective any such analysis needs to consider a broad range of metrics, baseline scenarios and possibilities for indigenous production of uranium in India. The uranium-policy space approach adopted here may be useful in that regard, even for similar analyses applied to other countries.

Finally, we have here focused exclusively on production of *weapons*-grade plutonium as a measure of proliferation risk. It is incumbent upon any work that does so to acknowledge that nuclear explosives can be fashioned from reactor-grade plutonium. Nonetheless, there are reasons to believe that weapons-grade material is preferable for at least some types of nuclear explosives.[32] Therefore it is reasonable to use the capability to produce weapons-grade plutonium as a first-order measure of proliferation risk.

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Endnotes

1 The White House, "Joint Statement Between President George W. Bush and Prime Minister Manmohan Singh," July 18, 2005 (http://www.whitehouse.gov/news/releases/2005/07/20050718-6.html, accessed October 20, 2006). The White House, "US-India Joint Statement," March 2, 2006, http://www.whitehouse.gov/news/releases/2006/03/20060302-5.html, accessed October 20, 2006. U.S. Department of State, "U.S. and India Release Text of 123 Agreement," August 3, 2007, http://www.state.gov/r/pa/prs/ps/2007/aug/90050.htm, accessed September 4, 2007.

2 Thomas Cochran *et al.* "Dear Member of Congress," June 20, 2006, www.npec-web.org/Essays/20060620-LetterOnArticleOne.pdf, accessed September 11, 2006 See Ashley J. Tellis, *Atoms for War?: U.S.-Indian Civilian Nuclear Cooperation and India's Nuclear Arsenal* (Washington, D.C., , Carnegie Endowment for International Peace), 2006, http://www.carnegieendowment.org/files/atomsforwarfinal4.pdf, accessed November 27, 2006, for further variants on this argument, attributed by Tellis (p. 6) to Henry Sokolski. In the cited work Tellis also gives a detailed material accounting intended to counter this argument. Notwithstanding, this assertion also appears in a November 13 open letter to members of the U.S. Senate (http://www.armscontrol.org/pdf/20061113_India_Letter_to_Senate.pdf, accessed November 24, 2006) entitled "Fix the Nuclear Trade Deal with India," in the form of the suggestion that "foreign supplies of nuclear fuel to India could assist India's bomb program by freeing-up its existing limited capacity to support the production of highly enriched uranium and plutonium for weapons."

3 Zia Mian, A. H. Nayyar, R. Rajaraman and M. V. Ramana, "Fissile Materials in South Asia and the Implications of the U.S.-India Nuclear Deal," *Science and Global Security*, 14 (2&3) (2006), 117-143. An earlier version of this work appeared as "Fissile Materials in South Asia: The Implications of the U.S.-India Nuclear Deal," Research Report No. 1, International Panel on Fissile Materials, September 2006, http://www.fissilematerials.org/ipfm/site_down/ipfmresearchreport01.pdf, accessed October 20, 2006.

[4] MNRR, *op cit.*, 135. In full context this assertion is conditioned on a significant increase in Indian uranium production, via the proposed Nalgonda mines, and on India "partially running one of its unsafeguarded power reactors at low burn-up."

[5] Joseph Cirincione, Jon B. Wolfstahl and Miriam Rajkumar, *Deadly Arsenals: Nuclear, Biological and Chemical Threats*, (Washington, D.C., Carnegie Endowment for International Peace) 2nd Ed., 2005, 221.

[6] Throughout the term "immediate future" means consideration of only those reactors operating or under construction, as of July 18, 2005. It is possible to base an evaluation of the proposed cooperation on other snapshots in time, but the immediate-future snapshot has the advantage that India has, in its separation plan (http://www.dae.gov.in/press/sepplan.pdf, accessed September 4, 2007), indicated which of the relevant reactors are to be designated as civilian facilities, and therefore eligible to be fuelled from the international market.

[7] In order to facilitate comparisons, considerations leading to the strategic-capacity constraints were based on values given in or inferred from MNRR. Specifically, the burnups for production of reactor-grade and weapons-grade plutonium were taken respectively as 7000 and 1000 MWth-days/tonne (p. 129), the capacity factor as 0.8 (p. 129), and the efficiency (electrical energy per unit thermal energy) as $.8\times2350\times365.25/338$ MWe-days/tonne $\div$ 7000 MWth-days/tonne (p. 129) = .29. Further, the annual capacity for electrical energy production, over the eight thermal power reactors currently operating or under construction and not to be safeguarded under the proposed U.S.-India cooperation, and therefore fuelled from indigenous Indian uranium, was taken as 2350 MWe $\times$ 365.25 days = 8.58×10^6 MWe-days (p. 125 of MNRR). The capability of the 100 MWth Dhruva reactor also was included in the strategic capacity.

[8] Refueling-rate and excess reactivity considerations are discussed by Tellis, *Atoms for War?*; cf. pp. 28 *ff.* and 31, respectively. MNRR also mention the former, on pp. 128 and 135; reactivity considerations do not seem to be explicitly addressed in MNRR, although the use of fuel bundles of partially depleted uranium is discussed (p. 129 *ff.*), which is one way of attempting to deal with the excess reactivity that would result from use of fuel otherwise subject to low burnup.

[9] This follows a suggestion of Tellis, *ibid.*, p. 31.

[10] There are eighteen Indian thermal power reactors currently operating or under construction assumed not to be fueled internationally without the proposed agreement. Here the annual capacity for these reactors was taken as $(6780\text{-}320\text{-}2000)*365.25 = 4160*365.25 = 1.519 \times 10^6$ MWe-days. The latter computation is based on the total 6780 MWe rating listed on the DAE web site (http://www.dae.gov.in/ → Power Generation → Nuclear Power Corporation of India, Limited, accessed October 21, 2006), less the ratings of the reactors that are assumed to be fueled from the international market even absent the proposed agreement. The latter are: Tarapur 1 & 2 (320 MWe), which are under international safeguards and have traditionally been fuelled internationally, and Kudankulam 1 & 2 (2000 MWe), which will be under international safeguards and (initially) fuelled by Russia. These considerations do not seem to be explicitly discussed in MNRR, presumably because the subsequent course of events under the status quo was not explored in detail there. In both Figures 1 and 2 the 100 MWth capacity of the Dhruva reactor was included in the total strategic capacity.

[11] *Op cit.,* 126. The premise is that this increase can be obtained through "likely new sites in the district of Nalgonda, in Andra Pradesh, with a potential capacity of about 150-200 tons of uranium a year" (*op cit.,* p. 127).

[12] India is, along with China and Pakistan, among the minority of uranium-producing countries that do not provide official reports on uranium production. In the absence of such official reports, the "Secretariat estimates" in the biennial OECD-NEAA/IAEA "Red Books" (latest edition: "Uranium 2005: Resources, Production and Demand," NEA No. 6098, (Paris, Nuclear Energy Agency, Organization for Economic Cooperation and Development) 2006) are widely accepted as authoritative. The following are those production estimates (in tonnes annually) back to 1990: 2005 (expected) - 230; 2004 - 230; 2003 – 230; 2002 – 230; 2001 – 230; 2000 – 207; 1999 – 207; 1998 – 207; 1997 – 250; 1996 – 250; 1995 – 155; 1994 – 155; 1993 – 118; 1992 – 150; 1991 – 200; 1990 – 230. The difference between this approximate 200 tonnes per year and the 300 tonnes quoted in MNRR. may simply be production losses, which often run about 1/3 over the multiple steps in going from ore to fuel bundles.

[13] Local and state opposition seem to be having an adverse effect on development of new mines; see T. S. Subramanian, "Uranium Crisis," *Frontline*, 22 (27), Dec. 31 – Jan. 13, 2006, http://www.flonnet.com/fl2227/stories/20060113000806000.htm, accessed November 21, 2006. Productivity at the Jaduguda mine, which is the historic flagship of India's uranium production, seems to have been in steady decline. (The most recent available *Red Book* (*op cit.*), estimates of that productivity, in tonnes of uranium ore per day, are: 2005 - 600; 2003 - 600; 2001 - 850; 1999 - 850; 1995 – 1000.) Efforts to reverse that decline could be difficult, because the steep incline of the ore-bearing deposit will require operation at challenging depths. The 2001 *Red Book, op cit.*, p. 185, states the two "lodes have an average dip of 40 to 45 degrees." Accordingly the UCIL

states that "the present shaft caters up to a depth of 555 metres and an auxiliary shaft up to 905 metres is being commissioned to mine deeper levels" (http://www.ucilindia.nic.in/ → Mines, accessed November 21, 2006.) This 900 meter depth seems extreme, especially in view of the relatively low grade of the ore.

[14] The actual policy decisions India must make regarding use of its indigenous uranium are more complex than simply choosing an operating point within the feasible region of a policy-space diagram such as Figures 1 or 2. Additional possible uses for this uranium include fuel for safeguarded reactors, production of enriched uranium for weapons, or for fuel for the publicly announced nuclear submarine program (GlobalSecurity.org, "Advanced Technology Vessel," www.globalsecurity.org/military/world/india/atv.htm, accessed November 25, 2006) or reserve against the possibility of even further (and presumably temporary) decline in domestic uranium production (see preceding paragraph). These considerations are neglected here, in the interest of providing a workable high-level conceptual framework that includes the quantitatively more significant potential uses of indigenous Indian uranium.

[15] See the references cited earlier, in regard to Proposition I. Subsequent to the 123 agreement signed on August 3, 2007, there were several offerings characterizing that agreement in terms of making a bad deal worse; cf. Editorial, "A Bad Deal Gets Worse," *New York Times*, August 5, 2007; Michael Krepon and Alex Stolar, "The US-India 123 Agreement: From Bad to Worse," The Henry L. Stimson Center, August 23, 2007, http://www.stimson.org/southasia/?SN=SA200708221446, accessed September 4, 2007.

[16] Based on, for the IF scenarios, the following 22 reactors, each with a nominal capacity of 220 MWe except as explicitly noted otherwise in parentheses: Tarapur 1 & 2 (160 MWe each), Rajasthan 1 & 2 (100 & 200 MWE, respectively) , MAPP 1 & 2, Narora 1 & 2, Kakrapur 1 & 2, Kaiga 1 & 2, Rajasthan 3 & 4, Tarapur 3 & 4 (540 MWe each), Kaiga 3 & 4, Rajasthan 5 & 6 and Kudankulam 1 & 2 (1000 MWe each). The Jl1805 scenario includes the first 14 of these reactors, although Tarapur 3 & 4 have subsequently begun commercial operation. The Jl1805 scenario is based on the first 14 of these. All data from the DAE web site, (http://www.dae.gov.in/ → Power Generation → Nuclear Power Corporation of India, Limited, accessed September 5, 2007).

[17] Here we assume that 1.11 tonnes of uranium at low burnup gives rise to 1 kg of weapons-grade plutonium, as consistent with the results shown in MNRR, *op cit.*, p. 135.

[18] On the other hand, one also can argue that the contribution of nuclear power toward meeting India's energy needs has been considerably inhibited by three decades of denial of access to the international market for nuclear materials and technology. With the end of this denial that is signaled by the pending agreement, one can reasonably expect growth in the relative contribution of nuclear to meeting India's energy needs. The viewpoint adopted here is that nuclear is not an undesirable source of energy, so that APC is a figure of merit, rather than of demerit. The validity of this view is a much debated point that is beyond the scope of the present note. However, the APC, or some similar metric, surely demands consideration in any comprehensive discussion of the pros and cons of the proposed nuclear cooperation.

[19] For example, "System Shutdown," *The Indian Express*, September 3, 2007, http://www.indianexpress.com/story/214166.html, accessed September 3, 2007.

[20] IAEA, *Limits to the Safeguards System*, http://www.iaea.org/Publications/Booklets/Safeguards/pia3810.html, accessed October 25, 2006.

[21] Cf. http://www.fas.org/nuke/guide/india/nuke/index.html (accessed September 4, 2007), and sources cited therein.

[22] These circumstances presumably include India national security considerations, in the face of two nuclear-armed neighbors with which it has some history of armed conflict.

[23] "Retaliation does not have to be instantaneous," Jaswant Singh, as quoted by C. Raja Mohan, "Interview with Jaswant Singh," *The Hindu*, November 29, 1999. An explication of Indian nuclear doctrine is given by Rajesh M. Basrur, "Minimum Deterrence and India Pakistan Nuclear Dialogue: Case Study on India**,"** LNCV South Asia Security Project Case Study 2/2006 (Como, Italy, Landau Network Centro Volta), March 2006, http://www.centrovolta.it/landau/South%20Asia%20Security%20Program.htm, accessed November 24, 2006. Appendices to this study contain the interview cited above, the never quite officially adopted Indian nuclear doctrine of 1999, and a clarifying January 2003 press release of the Ministry of External Affairs entitled "Nuclear Doctrine and Command and Control." For an even fuller treatment see Ashley J. Tellis, *India's Emerging Nuclear Posture: Between Recessed Deterrent and Ready Arsenal*, (Santa Monica, CA, RAND) 2001.

[24] The most widely quoted concise description of such a policy change is by K. Subrahmanyam, "India and the nuclear deal," *The Times of India*, December 12, 2005 (http://timesofindia.indiatimes.com/Opinion/Editorial/India_and_the_nuclear_deal/articleshow/msid-1327306,curpg-2.cms, accessed September 3, 2007): "Given India's uranium ore crunch and the need to build up our minimum credible nuclear deterrent arsenal as fast as possible, it is to India's advantage to categorise as many

power reactors as possible as civilian ones to be refuelled by imported uranium and conserve our native uranium fuel for weapon-grade plutonium production."

[25] See, for example, H. Blix, as reported by Sarah Smiles, "Weapons inspector fears new arms race," The *Age,* August 27, 2007 (http://www.theage.com.au/news/national/weapons-inspector-fears-new-arms-race/2007/08/26/1188066946419.html, accessed September 3, 2007).

[26] As foreshadowed in the preceding three paragraphs, a truly complete analysis of this type would incorporate indigenous uranium production and capacity to be fuelled indigenously into the underlying probability space, as policy choices available to India conceivably have some impact upon both of these.

[27] For example "the deal … tacitly acknowledges India as a nuclear-weapons state," Matthew Rosenberg, "Doubts grow over U.S.-India deal," *USA Today,* August 27, 2007 (http://asp.usatoday.com/community/tags/topic.aspx?req=tag&tag=New%20Delhi, accessed September 3, 2007).

[28] *Op cit.*

[29] For this scenario the feasible region has been obtained by replacing the uranium constraint by the NNWS/NPT constraint that the operating point must lie along the vertical (reactor-grade plutonium) axis.

[30] Here India's indigenous production rate of uranium as of this date is assumed to be 300 tonnes per year.

[31] Section 104 (g)(2) of the Henry J. Hyde United States-India Peaceful Atomic Energy Cooperation act of 2006, as presented by Congress to the President on December 13, 2006 and signed into law by the President on December 18, requires the President to submit to appropriate congressional committees, initially and annually thereafter, a report containing the following (italics added):

- "an analysis of whether United States civil nuclear cooperation with India is *in any way* assisting India's nuclear weapons program, including through … the provision of nuclear fuel in such a manner as to facilitate the *increased production* by India of highly enriched uranium or plutonium" (subparagraph (F)(iii));
- "an analysis as to whether imported uranium has *affected the rate of production* in India of nuclear explosive devices" (subparagraph (J)).

Such analyses are fraught with the potential for disagreement, because they require some comparative standard and metric, neither of which are specified in the legislation.

[32] See J. Carson Mark, "Explosive Properties of Reactor-grade Plutonium," *Science and Global Security*, 4 (1) 1993, 111-128; also Richard L. Garwin, "Explosive Properties of Various Types of Plutonium," in *Managing the Plutonium Surplus: Applications and Technical Options,* (Dordrecht, NATO and Kluwer, 1994, Richard L. Garwin, Michael Grubb and Emma Mantale, Eds.), 15-22; Peter G. E. F. Jones, "Explosive Properties of Various Types of Plutonium: Comments," in Garwin, Grubb and Mantale, *op cit.,* 23-25; and Gerald E. Marsh and George S. Stanford, "Bombs, Reprocessing and Reactor Grade Plutonium," *Forum on Physics & Society,* 35 (2) 2006 (American Physical Society, http://units.aps.org/units/fps/newsletters/2006/april/article2.cfm).