Fissile Material in South Asia

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Introduction

- First let me thank Professors Schaerf, Franceschini and Evangelista for the invitation to come here and for their very kind help in enabling me to travel to Andalo.
- Since this is a winter course ,not a conference, I had made my lecture a little pedagogical, explaining some of the basics. But after Mirco Elena's and Pavel Podvig's excellent presentations some of my slides were unnecessary and I have removed them.
- But, there may still be a little repetition. Please bear with that.

Motivation

- Fissile Materials sound profoundly boring.
- Why should you worry about them , instead of being at the ski-slopes right now?
- What are they, anyway ?
- And why S Asia? Is there something special about them (Yes there is! I will explain later)
- FM are the “gun powder “ of nuclear weapons. By undergoing fission, which generates huge amounts of energy in a fraction of a second, they are the source of the weapon’s enormous destructive energy

- Now, although a nuclear weapon has many technologically complex components, its FM core is the hardest to manufacture or get hold of , for any country or a non state actor wanting to acquire a nuclear weapon.
- I will shortly explain why .
- Therefore it is imperative that we pay attention to how much fissile material is located where, get a full and reliable inventory of them, safeguard them and find ways to eventually get rid of them
- For purposes of this talk, the only two species of FM are Uranium and Plutonium. Some other actinides can also undergo Fission , but they don't constitute the bulk of weapon fuel or its stocks.

Start with U

Two isotopes of U are fissile: U 233 and U235.

Over 99% of Natural U found under the ground is the non-fissile U238. It has only 0.71% of the fissile U-235 and even tinier amounts of U 233;

That is adequate for fuelling certain types of reactors, but not a bomb.

For that you have to "enrich" the uranium's U-235 content. Since you can't produce more 235, you enrich by separating out the unwanted U 238, rather like distilling whiskey.

This is done by using a battery of thousands of centrifuges – spinning drums rather like washing machines , but a tad faster (500 rps)

Grades of U

- Natural U (0.71% of U 235)
- Low Enriched U (LEU) < 20% of U-235
- (needed for Light water reactors as fuel)
- Highly enriched U (HEU) > 20% of U-235
- Weapon grade U > 90% of U-235
- (About 15-40 kg per 20 kT bomb)
- [Aside: The same set of centrifuges can be used, with some rearrangement, to produce either LEU for reactors and HEU for weapons. Hence the Iran controversy]

Grades of Plutonium

- Pu does not naturally occur at all as a mineral and has to be artificially produced .This is generally done in nuclear reactors.
- They (unavoidably) produce some Pu through the reaction
- n + U(238) → Pu(239) + e + v (ALCHEMY!!)
- This wont happen in every fission event, but there is a known probability for it happening

Reactor Grade Plutonium

- **Pu 239 is ideal for weapons, but if you leave the fuel rods in the reactor longer, some of this Pu 239 absorbs another neutron to become Pu 240 and later Pu 241.**
- **So you end up with a mixture of Pu isotopes, loosely termed Reactor Grade Plutonium (RGrPu)**
- **For example India's CANDU reactors, run at a burn of 7000 MWd/t produces a mixture of 50-60% Pu 239, 25% Pu 240 , some Pu 241 and Pu 238 starting from U235**

(RGrPu is in principle weapon-usable, but premature explosion due to spontaneous fission of Pu 240 can fizzle it. Also hotter and more radioactive because Pu 238, Pu 240, Am 241. Harder to handle)

- **Weapon Grade Pu: > 90% of Pu 239, < 7% of Pu 240**

To get WGrPu you have to pull out the feel rods before much of the Pu 239 changes to Pu 240 etc.

Called "Low Burn", this is a sub-optimal use of the fuel from the energy point of view

Why South Asia

- India and Pakistan are the two significant nuclear powers that still continue to produce fissile materials. The P5 (seem to) have stopped.

India's Production Reactors

India's WGrPu is produced in two "production" reactors: the 40 (MWth) CIRUS and the 100 MWth Dhruva. Both located in the Bhabha Atomic Research Center (BARC) , Mumbai

	Power (MWt)	Moderator	Coolant	Criticality Date/Full Operations	Long shutdown
CIRUS	40	D_2O	H_2O	1960/1963	1997-2003
Dhruva	100	D_2O	D_2O	1985/1988	-

Both reactors are believed to have fuel burnup of about 1000 MWd/t, which translates to 0.9 kgPu/tU

This is low burn-up. The normal burn-up of other CANDU power generating reactors is about 6700 MWd/t

Reprocessing of WGrPu

- The Pu so produced lies in the spent fuel rods. After the spent rods are taken out , the Pu has to be separated chemically from the rest of the rod's contents by "Re-processing".
- So, the reprocessing capacity can limit the stock of Pu.
- The spent fuel from CIRUS and Dhruva are reprocessed at a reprocessing plant inside BARC (our little Los Alamos),
- Its capacity is adequate to process all the spent fuel produced by CIRUS and Dhruva.
- So India's stock of separated Pu could be taken to be almost all of the Pu produced in the reactor.

Estimating India's WGrPu

- Estimating WgrPu stocks is in principle simple.
- For each fission event and in a given reactor design, there is a known probability that one of the emerging neutrons will convert a U-238 nucleus into Pu -239.
- So, to calculate the total amount of Pu produced in some period , you need only the total number of fission events, which in turn can be worked out from the energy generated by the reactor
- We know that installed capacity of Cirus and Dhruva were 40 MWth and 100 MWth. But this has to be multiplied by their capacity factor , i.e. the fraction of its Installed capacity that is actually produced.
- Public details of the operating histories of these reactors are sparse. One has to connect whatever few dots are available in the public realm

Wgr Pu Consumption and Balance

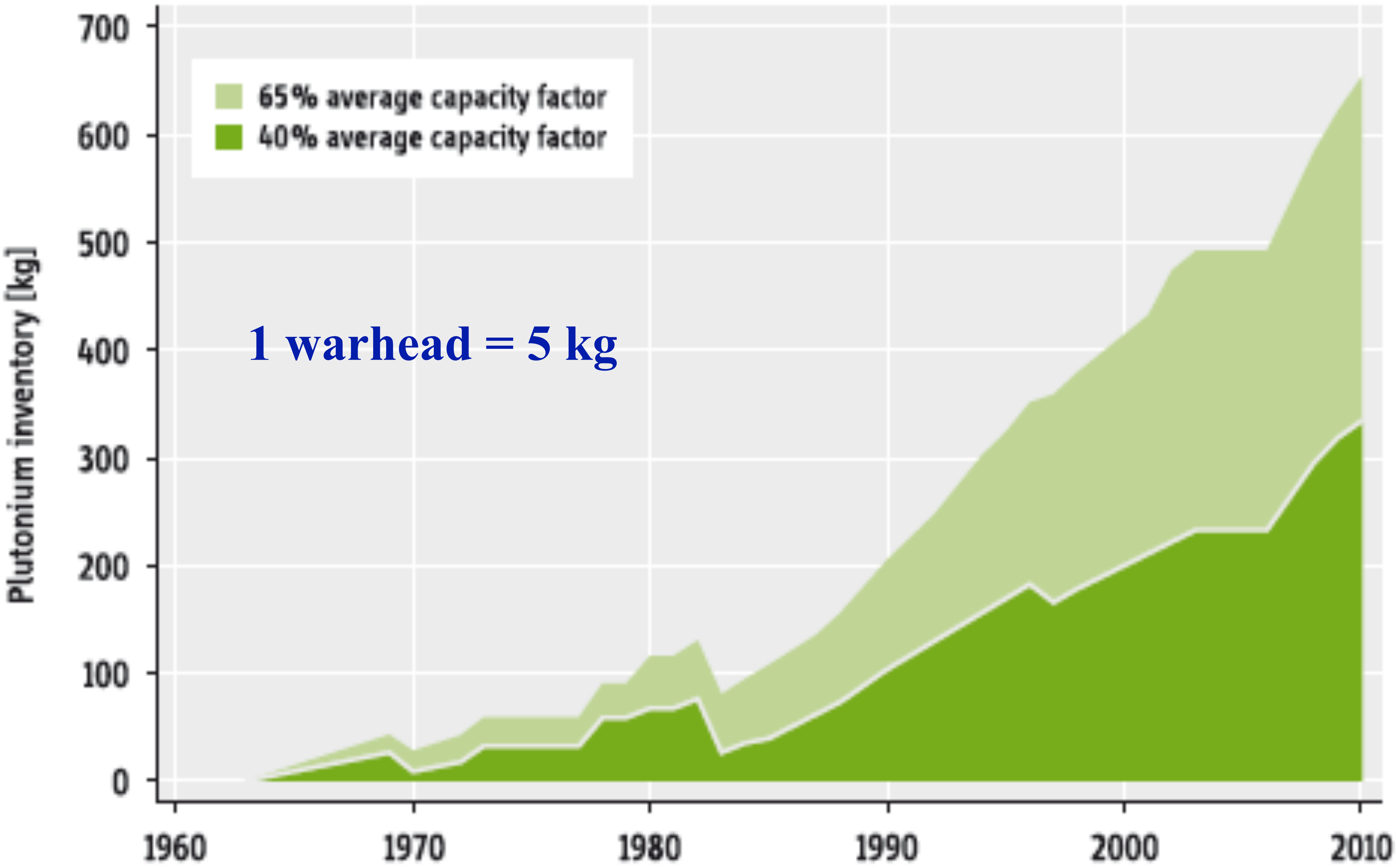
- 5-7 kg was consumed in the 1974 test
- The Fast Breeder Test Reactor was constructed before any unsafeguarded reactor-grade plutonium was available (till mid ‘eighties all reactors were safeguarded). Therefore FTBR was fueled with 50kg of WGr plutonium.
- 20-30 kg of weapon-grade plutonium was taken out of the stockpile in 1997 and used to construct the devices exploded in the 1998 nuclear weapon tests.

Updated WGrPu estimate
GFMR 2010
www.fissilematerials.org

	Higher Estimate	Lower Estimate
CIRUS and Dhruva production	630 kg	420 kg
Power Reactor first discharges	95 kg	-
Total consumption	-76 kg	-87 kg
Total stockpile	650 kg	330 kg

The higher estimate is at 65% capacity factor and assumes that the early discharge from the power reactors was successfully separated . The lower estimate is at 40% capacity factor and assumes higher consumption in the 1974 and 1998 tests.

Cumulative WGrPu



Reactor Grade Pu

- The R Gr Pu stocks are produced in the different power reactors in the country, which are run a normal burn of about 6700 MWd/t
- But not all the stocks are available for military purposes. Some are safeguarded.
- The safeguard status has been re-negotiated after the Indo-US nuclear Deal and the NSG waiver

Indian Power Reactors in operation 2006

5 military & 10 safeguarded (4 already)

Power reactor	Type	Power (MWe)	Date of commencement	Safeguards (as of February 2006)	Future Safeguard status
Kaiga-1	PHWR	220	16-Nov-00	Unsafeguarded	Military
Kaiga-2	PHWR	220	16-Mar-00	Unsafeguarded	Military
Kakrapar-1	PHWR	220	6-May-93	Unsafeguarded	2012
Kakrapar-2	PHWR	220	1-Sep-95	Unsafeguarded	2012
Madras-1	PHWR	170	27-Jan-84	Unsafeguarded	Military
Madras-2	PHWR	220	21-Mar-86	Unsafeguarded	Military
Narora-1	PHWR	220	1-Jan-91	Unsafeguarded	2014
Narora-2	PHWR	220	1-Jul-92	Unsafeguarded	2014
Rajasthan-1	PHWR	100	16-Dec-73	Safeguarded	Safeguarded
Rajasthan-2	PHWR	200	1-Apr-81	Safeguarded	Safeguarded
Rajasthan-3	PHWR	220	1-Jun-00	Unsafeguarded	2010
Rajasthan-4	PHWR	220	23-Dec-00	Unsafeguarded	2010
Tarapur-1	BWR	160	28-Oct-69	Safeguarded	Safeguarded
Tarapur-2	BWR	160	28-Oct-69	Safeguarded	Safeguarded
Tarapur-4	PHWR	540	12-Sep-05	Unsafeguarded	Military

Reactors under construction

Kaiga-3	PHWR	220	2007 (planned)	Unsafeguarded	Military
Kaiga-4	PHWR	220	2007 (planned)	Unsafeguarded	Military
Kudankulam-1	VVER	1000	2007 (planned)	Safeguarded	Safeguarded
Kudankulam-2	VVER	1000	2008 (planned)	Safeguarded	Safeguarded
Rajasthan-5	PHWR	220	2007 (planned)	Unsafeguarded	2007
Rajasthan-6	PHWR	220	2008 (planned)	Unsafeguarded	2008
Tarapur-3	PHWR	540	2007 (planned)	Unsafeguarded	Military

Altogether 14 safeguarded (4380 MWE) and 8 military (2350 MWe)

Reprocessing units

- Pu Reprocessing plants
- Trombay 50 HMt/yr.
- Used for WGr Pu from CIRUS, Dhruva)

- Kalpakkam (1998) 100 HMt/yr
- Effective capacity factor assumed to be 53%

- Tarapur (1987) 100 HMt/yr
- Effective capacity factor assumed to be 53%

Cumulative separated RGrPu

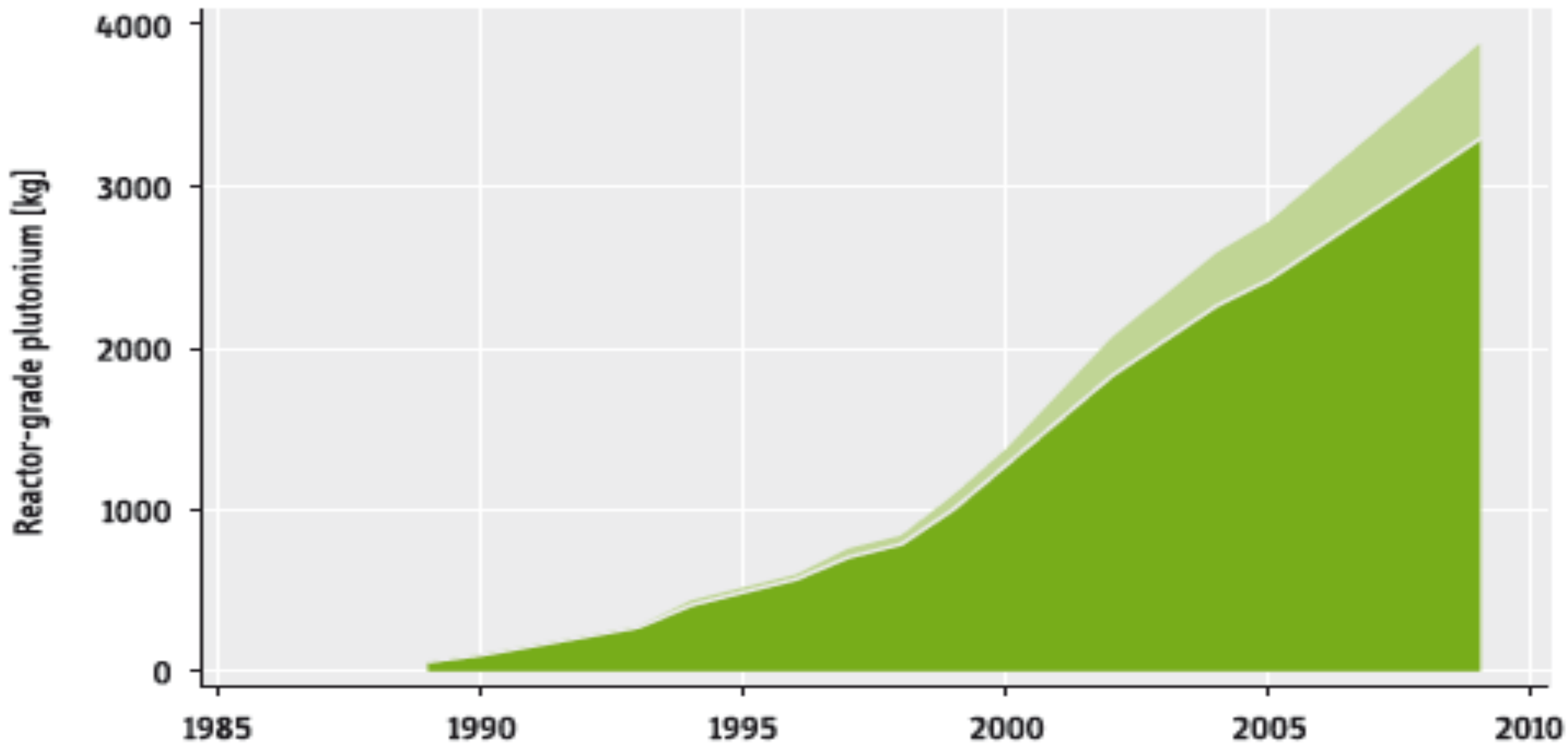


Figure 9.3. Cumulative production of separated reactor-grade plutonium. The lower estimate (3.3 tons) corresponds to a burnup of 7000 MWd/t with the PREFRE and KARP reprocessing facilities operating at average capacity factors of 44 % and 48 % respectively. The higher estimate (3.9 tons) corresponds to a burnup of 6600 MWd/t with KARP and PREFRE operating at higher average capacity factors of 65 % and 49 % respectively

In addition, 5.5 tons of un-separated RGr Pu sitting in 2400 tons of un-safeguarded spent fuel

India's Uranium enrichment program

- A centrifuge plant (" Rare Materials Project "), reportedly has been operating at Rattehalli in southern India since 1990.
- It is generally believed that it enriches HEU to 30-45% and is meant for India's Nuclear Submarine

- One pilot scale enrichment plant at the BARC complex and an industrial scale one at Rattehalli (code: Rare Materials Plant)
- Latter has been operating since 1990

Time line of development

(M.V. Ramana's analysis in IPFM annual report 2010)

www.fissilematerials.org

- In early 1990s From early reports, 300 to 800 machines with capacity 1.5 to 2.5 SWU/y each were set up, giving an enrichment capacity in the range of 450 to 2000 SWU/y.
- Late 1990s to 2007: increased to 12000- 19000 SWU
  by adding Generation II centrifuges
- 2007-09: additional 7000-13,000 SWU
  using Gen III (7-13 SWU each),
- Total capacity as of 2010: 19000-32000 SWU/yr
- Albright & Basu (ISIS),
- Constraints on HEU from fueling the test core of
- submarine reactor in 2000 and
- Government statements

Estimate of HEU Stocks and Production

- The estimated HEU production so far is 840 to 1750 kg for an enrichment level of 30% with 0.3% tails.
- If the enrichment level is 45%, again with 0.3% tails, the total HEU production estimate is 540 to 1130 kg

Summary of un-safeguarded FM stocks

- Plutonium stocks
- weapon-grade plutonium of 330 to 650 kg,
- a separated Reactor-grade plutonium stockpile of 3.3 to 3.9 tons.
- 5.5 tons of un-separated Reactor Gr Pu sitting in 2400 tons of un-safeguarded spent fuel
- HEU stocks
- As of 2010, India is estimated to have a stockpile of 839 to 1747 kg of HEU at an enrichment level of 30%,
- or 543 to 1131 kg at an enrichment level 45%,

Future Production of WGrPu

- CIRUS is being shut down. That leaves only the Dhruva, producing about 20kg of WGrPu per year.
- Once the Fast Breeder comes into operation (2011?) and output from its U blanket and core is available (2015?), the production of WGrPu in will go up drastically.
- If only the radial blanket is reprocessed, it will yield about 90kg /yr, while the axial blanket would yield an additional 50kg/yr
- Total : 110 to 140 kg of WGrPu/yr
- But it is not clear if India plans to build more warheads with the PFBR output, or simply re-use it a fuel.

- HEU: Current capacity can produce annually, with 0.3% tails
- 500kg of 30% HEU, or
- 200 kg of 45% HEU,
- RGrPu: 650 kg annually after 2014, when only eight PHWRs with a total capacity of 2.35 GWe will remain un-safeguarded.

Onward, briefly, to Pakistan

RR ,Zia Mian and A.H.Nayyar

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Only Available official information

- Annual indigenous uranium production (imports are not allowed because of sanctions)
- Civilian Energy is produced by the safeguarded power reactor KANUPP
- **Unconfirmed information in the literature**
- Pu production reactors, Khushab-1, -2 and -3
  - Khushab-1 power assumed 50 MWth
- Reprocessing
  - New Labs, no information on size and capacity
  - Chashma reprocessing plant, renewed activity on the site
- Enrichment capacity
  - Old estimates (circa 2000) from Albright *et al.*, 15,000 kg SWU/year

(somewhat wild)Speculations in the literature

- Very large enrichment capacity; Kahuta plant replicated
  - Names like Golra, Gadwal, etc, often floated
  - Reports of the use of P3 and P4 centrifuge machines
- Very large capacity for Khushab-3 production reactor
  - up to 1000 MWth, producing 200-250 kg of plutonium

Our Assumptions

- Continuing local uranium production @ 40 tons/year
- All Khushab reactors will be 50 MWth
- Enough front end capacity: fuel fabrication, UF6 conversion, heavy water, etc
- Enough back end capacity: reprocessing

Enrichment history

- First HEU produced 1983
- by 1984 they had produced enough uranium for a nuclear test
- By 1986 Kahuta had a nominal capability to produce “enough weapons grade material to build several nuclear devices per year”
- Interruption in enrichment in mid-1989 due to Pakistan Prime Minister’s visit to the US;
- Enrichment resumed in spring 1990
- US sanctions imposed in 1990, Pakistan declared a moratorium on HEU production and produced only 5% LEU from 1991
- 5% LEU production continued until nuclear tests in mid-1998, after which Pakistan resumed HEU production.
- The LEU stock would also have been enriched to 90%

Assumptions about enrichment capacity

Started with

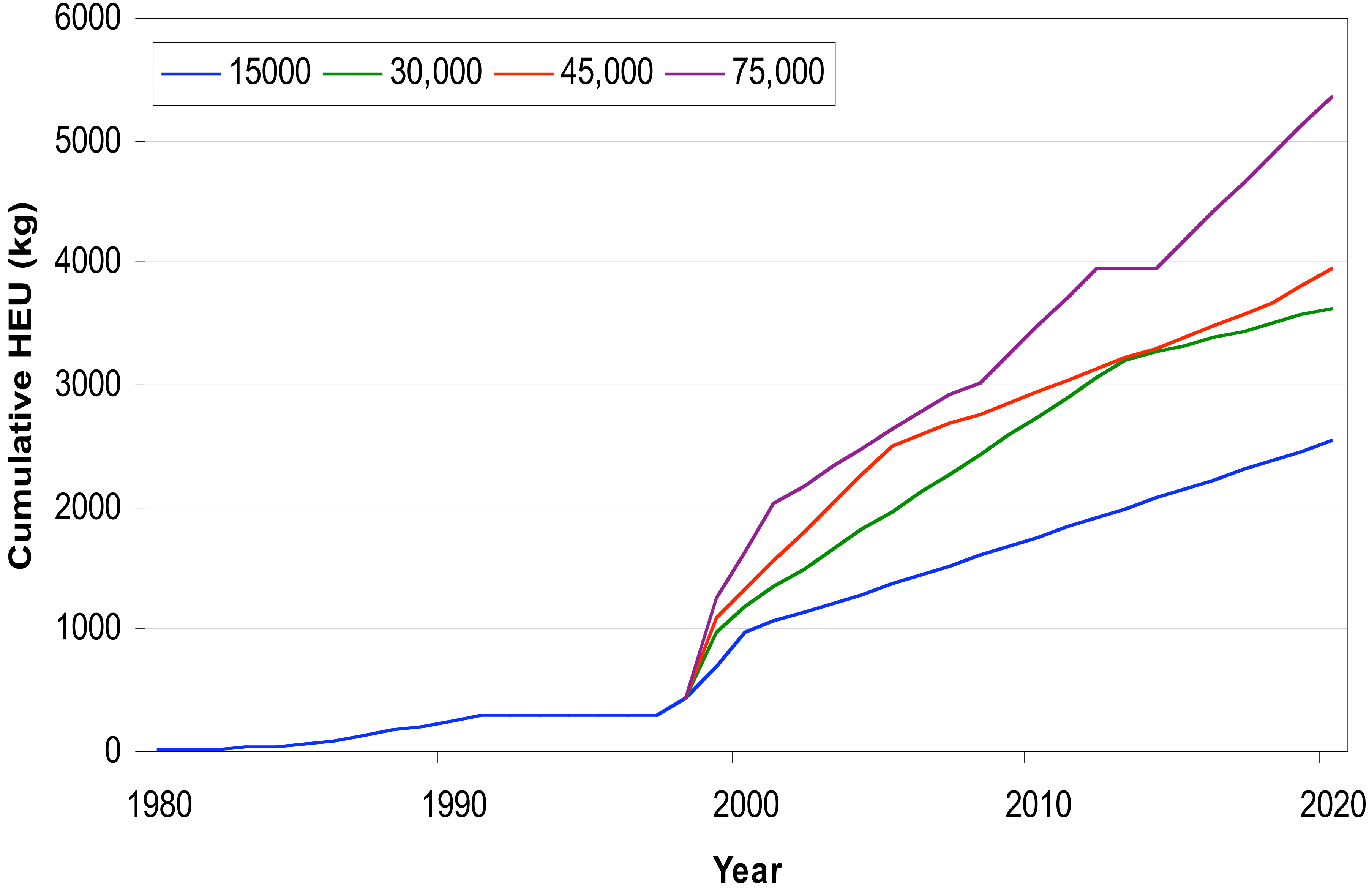
- Dutch machines SNOR and CNOR
  Pakistani P-1 machines, 2-3 kg SWU/y
- German G-1 and G-2
  Pakistani P-2 machines, 3-5 kg SWU/y

Later inclusion

- P-3 machine based on Urenco 4 M, 12 kg SWU/y
- P-4 machine based on TC-10 of Ultracentrifuge Nederlands, 20 kg SWU/y

Pakistani cascade design (probably also sent to South Africa for Libya)

- 5832 machines (about 6000)
- Or half as many 2916 (about 3000) (P1 or P2 machines)
- With 3-5 SWU per machine, total ~ 9,000 – 15,000 SWU consistent with the estimates of Albright et al.



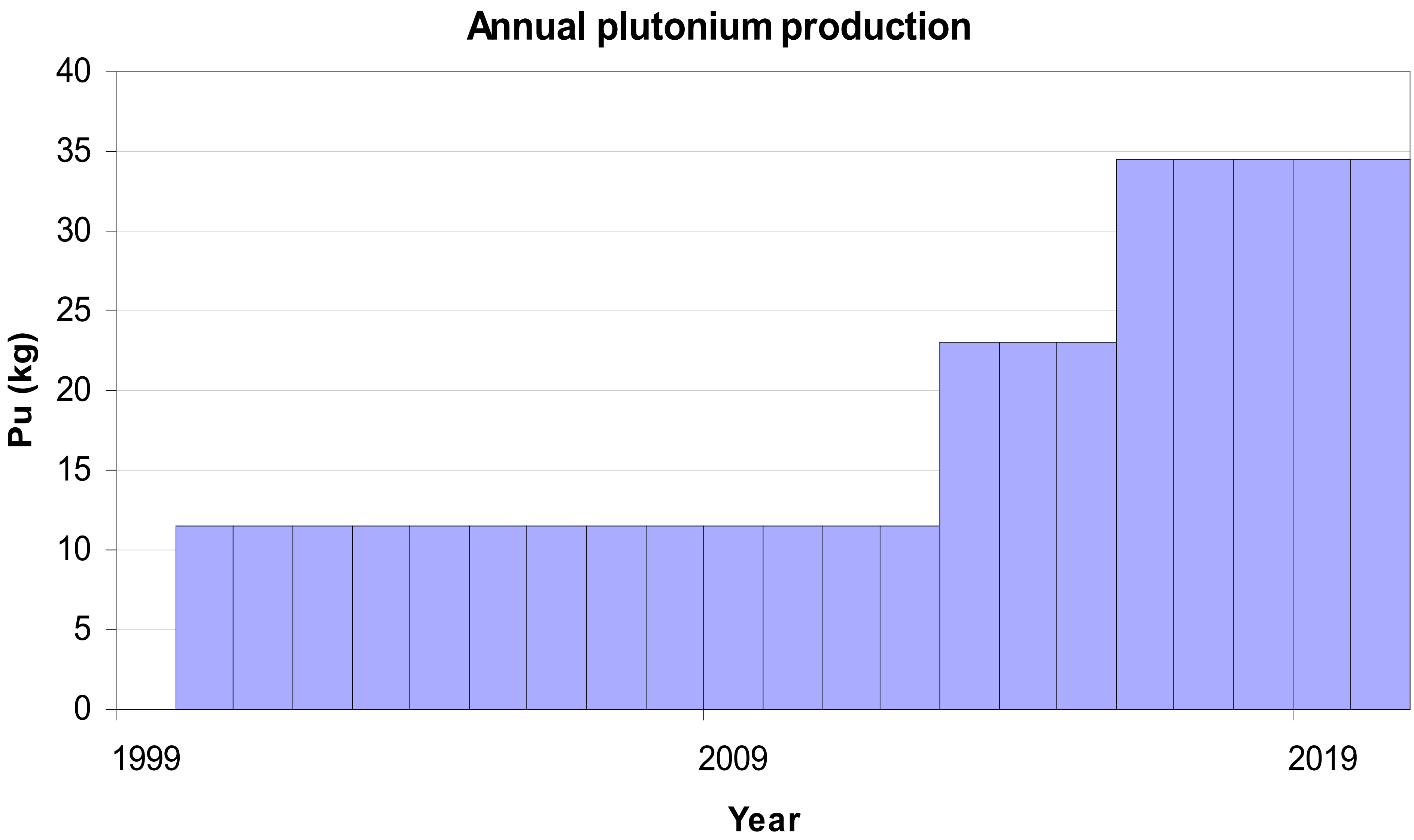
6000
5000
4000
3000
2000
1000
0
15000
30,000
45,000
75,000
Cumulative HEU (kg)
1980
1990
2000
2010
2020
Year

The plutonium program

- In the meantime, in 1998, Khushab-1 becomes operational, requiring 13 tons of natural uranium fuel per year.
- Khushab-2 assumed operational by 2011. It would need 13 tons per year of uranium fuel starting 2010.
- Khushab-3 is assumed operational by 2014.

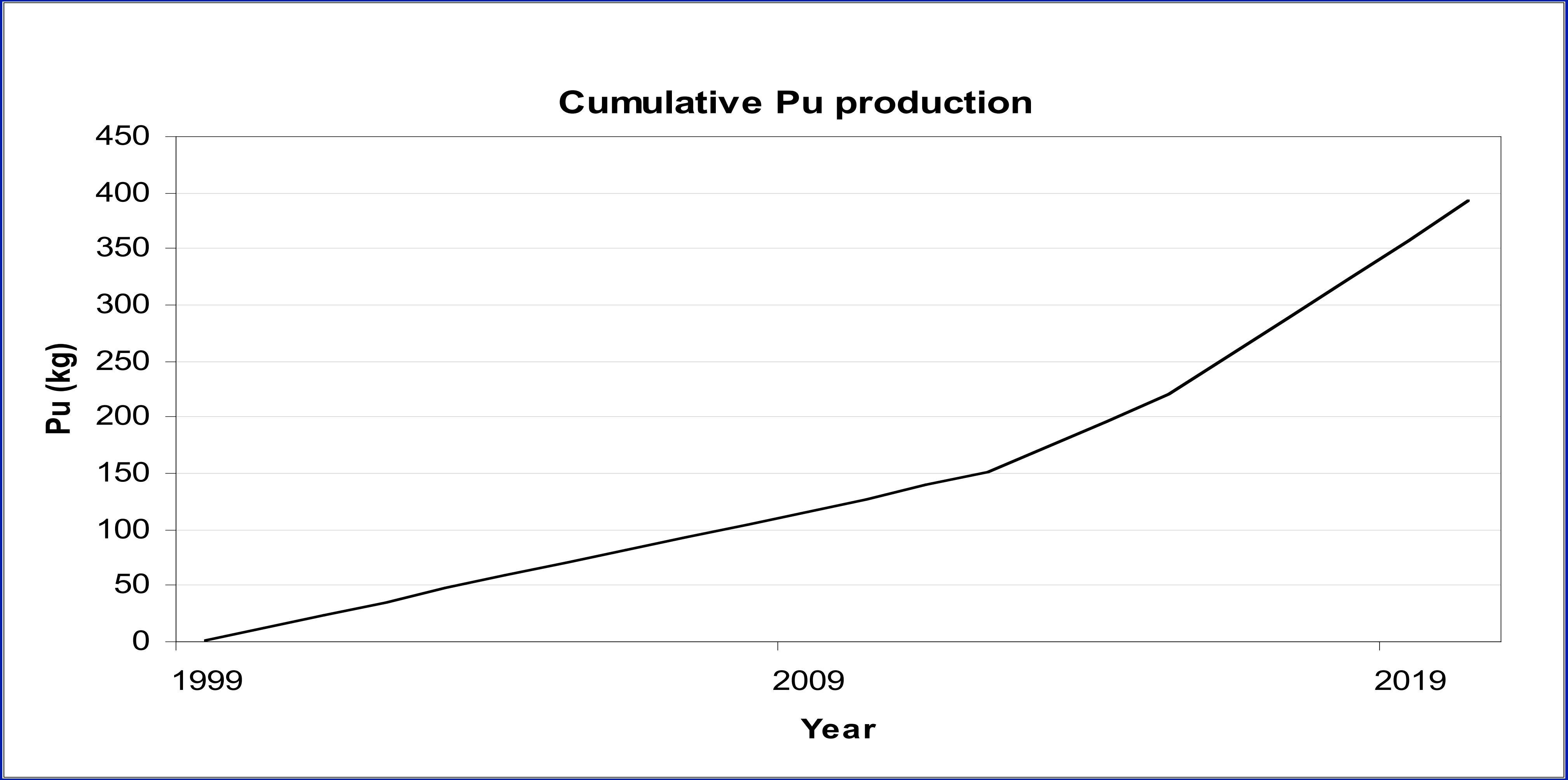
- The three reactors would together consume nearly all of the 40 tons of indigenous natural uranium per year.

- The stockpile of natural uranium would quickly get consumed.



Starting 2016 about 35 kg of WGr Pu (7 weapons) a year

Cumulative WGr Pu production



By now, about 115kg ≈ 23 weapons

By 2020, 400kg ≈ 80 weapons

Conclusions

- Pakistan may have by now accumulated 1.5 - 3 tons of HEU, and the stocks may rise to 2.5 – 5.5 tons of HEU by 2020.
- It also has about 100 kg of Pu, and may have nearly 400 of Pu by 2020.
- Pakistan’s capacity to enrich uranium is severely limited by domestic uranium supplies. Its military enrichment program would not gain anything by increasing the capacity beyond 75,000 kg SWU/year.
- Starting from about 2013, the three Pu production reactors will consume all the annual natural uranium production. Therefore, the enrichment plant(s) would need alternative feed after this. Options are: tails from earlier enrichment, and reprocessed uranium recovered from the production reactor spent fuel.

THE END

Official Indian position on FMCT (Caution: Not MY position !!)

- Historically, India has supported the evolution of some form of a fissile material control regime in principle for a long time.
- India co-sponsored the UNGA resolution 48/75L, in 1993, which contained the mandate to negotiate an FMCT. This support was reiterated by India after the Conference on Disarmament (CD) adopted a negotiating mandate in 1995,and in 1998, following the establishment of a negotiating committee.
- This commitment was repeated by the Indian Prime Minister in the Indian Parliament in 2007, "We remain committed to a voluntary, unilateral moratorium on nuclear testing. We are also committed to negotiate a Fissile Material Cut-off Treaty or FMCT in the Conference on Disarmament. …"
- But he went on to qualify this by "…India is willing to join only a non-discriminatory, multilaterally negotiated, and internationally verifiable FMCT, as and when it is concluded in the Conference on Disarmament, subject to it meeting our national security interests. "

No Moratorium on FM production for now

- So, Notwithstanding in-principle long-term support for FMCT, India is unwilling at this time to impose on itself a voluntary moratorium on producing more fissile materials for weapon purposes.

- India has not hidden its unwillingness to stop fissile materials production. This is clear from its negotiating position in the Nuclear Deal with the US , which essentially implied that in its judgment its current stocks of fissile materials plus the future output of its existing two research reactors (CIRUS and Dhruva) that produce weapon-grade plutonium were not sufficient for its strategic needs

Reasons behind Indian position

- The difference between the Indian and probably also the Pakistan positions and that of the NPT nuclear-weapon states on a fissile-material moratorium is not hard to explain.
- The latter have already built nuclear arsenals as large as they expect to need in the foreseeable future.
- The US and Russia have downsized their nuclear weapon inventories by more than twenty thousand each, while the UK has brought its arsenal down to less than 200 sea-based warheads.
- China seems to have stopped production of fissile materials, but has not made an official declaration of a unilateral moratorium. A plausible explanation is that it wants to keep open its options of producing more fissile material should its security environment change in the future. The most frequently cited concern is a U.S. ballistic-missile defense system that brings into question China's deterrent.

Our assessment of the Indian position

- By contrast, the implicit Indian view appears to be that it is a recent entrant to the group of nuclear powers, that its nuclear forces are still at the growing stage and that it needs more time before it can consider any constraints on its fissile-material production.
- As with any other sovereign nation, India’s posture towards different planks of any proposed FMCT will be dictated by its strategic concerns.
- It is unlikely that India will accept any restriction on its production till such time as it feels that it has an adequate nuclear arsenal to deter all foreseeable nuclear threats to its security.
- India’s posture during any FMCT negotiations on the critical issues of existing stocks and verification will also be influenced by its estimate of its requirements.

The Future ?

- Once India is convinced that it has enough warheads and a back-up stockpile of fissile material for its declared doctrine of minimum deterrence, one can hope that it will be willing, like the NPT nuclear-weapon states, to stop further production.
- It may also be willing to declare a part of its existing stockpile of reactor-grade Pu "excess" to its military needs.
- (Caution: This is only MY hope!)
- The problem is deciding how much is enough.
- I believe that what they have is more than enough for the stated purpose of minimal deterrence, But no takers
- But I get laughed at a lot less by India's strategic community and get less hate mail.

Prospects — not hopeless

- We must remember that national security decisions of countries are not always based on precisely tailored requirements. Governments like to play safe and stock up with more weaponry than is needed, rather than be guilty of "compromising national security".
- Besides, it takes some "turn around time", politically and psychologically, before India can close its nuclear program. Recall that the US took over 40 years, and China 30 years before they stopped producing FM. it is less than 10 years since India became overtly nuclear.
- So I feel there some hope that India may also do so in a few years, by the time an FMCT treaty is ready.
- Finally, the response of many nations, including India (and Pakistan) to new nuclear regimes like the FMCT will be favorably influenced by speedier progress in worldwide disarmament.

➤ THE END