ASIA

Asia's rival reactors a cause for concern

Canada has come clean on its contributions to the Indian and Pakistani nuclear programmes, confirming fears that the region's potential for further weaponisation is greater than generally acknowledged. **Ian Steer** reports.

New information provided by the Canadian Nuclear Association (CNA) on the performance of Canadian Deuterium Uranium (CANDU) nuclear reactors in India and Pakistan has shed additional light on the size of weapon material inventories in both countries.

India

As of 1 July 1998, India's 10 nuclear power reactors, eight of which are CANDUs, and three of her six nuclear research reactors, one of which is Canadian, have produced 3,299kg of plutonium. Seventeen per cent of this, or 567kg, is weapons-grade plutonium; the rest is 'reactor-grade'. Although reactor-grade plutonium is less efficient for nuclear weapons, India's plutonium, as is, could potentially be used to make 455 atomic bombs.

This estimate contrasts sharply with the majority view that India can produce from 25 to at most 65 nuclear weapons (see *JIR*, July 1998, pp 23-25). Such a view, however, includes only weapons-grade plutonium from India's nuclear research reactors. As of July these reactors have produced 113 critical masses. They produce 7.5 new critical masses every year. This estimate is based on CNA data along with recent information from the Institute for Science and International Security (ISIS) and the Natural Resources Defence Council (NRDC): two Washington DC-based research groups.

Conservative estimates do not include reactor-grade plutonium from India's nuclear power reactors. Is this plutonium's military potential overlooked by the region's leaders? Few analysts have checked. Dr W P S Sidhu reported in *JIR*'s July issue that if reactor-grade plutonium is taken into account, India is now capable of producing at least 390 and as many as 470 nuclear warheads (see *JIR*, July 1998, pp 23- 25). This article confirms and adds insight into Dr Sidhu's suspicions.

Pakistan

It is widely believed that the nuclear weapon materials in Pakistan are sufficient to produce at most 25 atomic bombs (see *JIR*, July 1998, pp 26-27). Yet the data in this article suggests that Pakistan is now capable of producing more than 100 atom bombs – or four times the number previously estimated.

Lower estimates do not take into account 38 critical masses worth of plutonium produced at Pakistan's one nuclear power reactor, a CANDU. In addition, closer analysis of Pakistan's two uranium enrichment plants indicates their combined production to date is two-and-a-half times greater than previously believed.

'Ultra' conservative estimates suggest Pakistan is capable of producing fewer than 12 nuclear weapons. Such suggestions however, are based on a statement made by Dr A Q Khan, 'father' of Pakistan's nuclear weapon programme, who said his country has "more than twice as much weapons-grade material left as was used in her six nuclear tests". Ergo, Pakistan now has a dozen nuclear weapons (see *JIR*, July 1998, pp 26-27). However, would the head of Pakistan's clandestine nuclear weapon programme divulge information that to every other nuclear weapon state in the world is a highly classified secret? Probably not. It is more likely that Dr Khan's comment represents a deliberate attempt (though slight, since by saying "more than", it is not a lie) to disseminate disinformation on Pakistan's actual weapon potential.

More bang for the buck

The number of nuclear weapons that can be made from a given inventory of nuclear materials can be maximised by using newer weapon designs. Modern nuclear weapons achieve 'more bang for the buck' by using less than a critical mass per weapon. Older weapon designs use more materials – close to a full critical mass each. For weapons-grade (90 per cent pure) plutonium 239, the 'bare critical mass' is 10kg; for uranium 235, it is 52kg. 'Fat Man', the first plutonium-based atomic bomb, and 'Little Boy', the first uranium-based weapon, used respectively two thirds of and a single bare critical mass each.

NRDC data published in 1984 revealed that modern nuclear weapons cores are surrounded by easily obtainable natural uranium (to reflect neutrons and increase the nuclear reaction). Thus, the critical mass can be lowered: for plutonium 239 to less than half and for uranium 235 to less than a third of their bare critical mass. The lower critical mass is known as the 'reflected critical mass'. For plutonium 239 it is 5kg; for uranium 235 it is 15kg. In addition, the reflected critical mass can be lowered by various forms of neutron injection and better conventional explosives to compress the materials to greater density. A critical mass reduced in this way is known as a 'fractional critical mass'.

On the other hand, if nuclear materials of less than 90 per cent purity are used, the amount of material required for a reflected critical mass goes up as the purity goes down. For plutonium 239 of only 80, 70 or 60 per cent purity, the reflected critical masses rise to 6, 7 and 8kg respectively. For uranium 235 at the same percentages the reflected critical masses are 21, 27 and 36kg. British and US nuclear tests in the 1960s proved that plutonium 239 of 60 per cent purity can be used to make weapons, although its explosive yield of just over 1kT per bare critical mass is small compared with 20kT for weapons-grade plutonium.

India's critical masses

India's nuclear weapons use plutonium. India's 1974 nuclear test used plutonium produced in the country's first nuclear reactor, the Canada India Research United States (CIRUS), a research reactor with 13MW of electrical power (40MW thermal) operating since 1963. If used to generate electricity, this reactor would be 'slow fuelled'.

'Slow' means fuel is 'burned' until fully spent at around two to three years. Although more efficient for generating power, irradiating fuel for that long causes impurities to build up in the plutonium created. As a result, slow- fuelled reactors produce 'reactor-grade' plutonium, which contains only 60 per cent of the plutonium 239 isotope suitable for weapons. The rest is non-weapons-grade plutonium 240, 241 and 242.

To produce 90 per cent pure plutonium 239, plutonium production reactors 'burn'

Ian Steer is a Toronto-based writer and author specialising in defence and science.

PAKISTAN

Nuclear weapons materials production facilities in Pakistan, and their output as of July 1, 1998

Production Facilities	Plutonium / Uranium Output in kilograms per year and to date	Critical Masses Per Yr	To Date
NUCLEAR REACTORS			
PARR	3 MWe (10MWt) x ? kg/yr x ? FP = ? kg/yr x 34.5 yr = ? kg	?	?
KANUPP	137 MWe x 0.3 kg/MWe-yr x .290 FP = 12 kg/yr x 25.00 yr = 300 kg Pu_{239} @ 60%	1 1/2 x 1-kT	38 x 1-kT
Khushab	17 MWe x 1.0 kg/MWe-yr x .500 FP = 9 kg/yr x ? yr (new) = ? kg Pu_{239} @ 90%	1 x 20-kT	? x 20-kT
MNSR	9 kWe (27kWt) x ? kg/MWe-yr x ? FP = ? kg/yr x ? yr = ? kg	?	?
	21 kg/yr + 300 kg Total Pu_{239} @ 60%	= 2 1/2/yr + 38 Critical Masses	
URANIUM ENRICHMENT PLANTS			
Sihala	45 kg/yr x .3333 Optg. Eff. = 15 kg/yr x 27.08 yr = 406 kg U_{235}	1 x 20-kT	27 x 20-kT
Kahuta	21 kg/yr per 1,000 centrifuges x 10,000 x .3333 Optg. Eff. = 70 kg/yr + 5,000 x .3333 Optg. Eff. x 17 yr = = 595 kg U_{235}	5 x 20-kT	40 x 20-kT
	85 kg/yr + 1,001 kg Total U_{235}	= 6/yr + 67 Critical Masses	
	239 235	= 8 1/2/yr + 105 Critical Masses	

I Steer/0037230

their fuel for a third of a year or less. 'Fast fuelling' prevents the build-up of plutonium impurities. Also, two thirds to three or more times more plutonium is created per megawatt because plutonium builds up more rapidly in fresh fuel.

Fast fuelled, CIRUS makes approximately 1kg of weapons-grade plutonium per year for each megawatt of power. With 13MWe, it can in theory create 13kg of plutonium annually. True plutonium output depends on how much time a given reactor spends at full power (FP), which for CIRUS is unknown. The CNA suggests this reactor's time at FP is probably similar to that of India's power reactors at around 50 per cent. Assuming this level of efficiency, CIRUS's actual output of weapons-grade plutonium could be around 6.5kg a year. Multiplied by its 34.75 years in service, CIRUS has potentially produced 226kg to date – or enough for 45 critical masses.

"Dhruva has been producing weapons-grade plutonium since the mid-1980s," said the NRDC's Thomas Cochran. "Assuming it could be run at maximum capacity, Dhruva is theoretically capable of producing 33kg of plutonium per year." An unofficial figure for Dhruva's time at FP was obtained by ISIS in 1992. Using a figure of 60 per cent FP, Dhruva would produce around 20kg of plutonium a year. Over its 11 years of full service, it would have produced close to 220kg to date – or enough for 44 atomic bombs.

India's newest research reactor, the 15 MWe (40MWthermal) Fast Breeder Test Reactor (FBTR), began operating in 1987. Similar to France's 40 MWe Rapsodie, this plutonium breeding reactor is capable of producing more plutonium than it consumes. Estimating its theoretical output at 1.5kg/MWe-yr, and assuming its time at FP (unknown) is around 50 per cent, the FBTR would have produced more than two critical masses a year – enough for 24 to date over its 11 years of full service.

INDIA

Nuclear weapons materials production facilities in India, and their output as of July 1, 1998

Production Facilities	Plutonium / Uranium Output in kilograms per year and to date	Critical Masses Per Yr	To Date
NUCLEAR RESEARCH REACTORS			
CIRUS	13 MWe x 1.0 kg/MWe-yr x 0.500 FP = 6.5 kg/yr x 34.75 yr = 226 kg Pu_{239} @ 90%	1 1/4 x 20-kT	45 x 20-kT
Aspara	1 MW(t?) x ? kg/yr x ? FP x ? yr = ?	?	?
Zerlina	0 MW (net) x ? kg/yr x ? FP x ? yr = ?	?	?
Purnima II	5 kWe x ? kg/yr x ? FP x 14 yr = ?	?	?
Dhruva R-5	33 MWe x 1.0 kg/MWe-yr x 0.600 FP = 20 kg/yr x 11 yr = 220 kg Pu_{239} @ 90%	4 x 20-kT	44 x 20-kT
FBTR	15 MWe x 1.5 kg/MWe-yr x 0.5000 FP = 11 kg/yr x 11 yr = 121 kg Pu_{239} @ 90%	2 1/4 x 20-kT	24 x 20-kT
	38 kg/yr + 567 kg Total Pu_{239} @ 90%	= 7 1/2/yr + 113 Critical Masses	
URANIUM ENRICHMENT PLANTS			
Ratnahally	? kg/yr x ? Optg. Eff. = ? kg/yr x ? yr = ?	?	?
NUCLEAR POWER REACTORS			
TAPS 1	210 MWe x 0.09 kg/MWe-yr x 0.479 FP = 9.1 kg/yr x 31 yr = 282 kg Pu_{239} @ 60%	1 1/8 x 1-kT	35 x 1-kT
TAPS 2	210 MWe x 0.09 kg/MWe-yr x 0.484 FP = 9.1 kg/yr x 30 yr = 273 kg Pu_{239} @ 60%	1 1/8 x 1-kT	34 x 1-kT
RAPS 1	100 MWe x 0.3 kg/MWe-yr x 0.229 FP = 6.9 kg/yr x 24.54 yr = 169 kg Pu_{239} @ 60%	0 7/8 x 1-kT	21 x 1-kT
RAPS 2	200 MWe x 0.3 kg/MWe-yr x 0.597 FP = 36 kg/yr x 17.25 yr = 621 kg Pu_{239} @ 60%	4 1/2 x 1-kT	78 x 1-kT
MAPS 1	170 MWe x 0.3 kg/MWe-yr x 0.494 FP = 25 kg/yr x 14.41 yr = 360 kg Pu_{239} @ 60%	3 1/8 x 1-kT	45 x 1-kT
MAPS 2	170 MWe x 0.3 kg/MWe-yr x 0.508 FP = 26 kg/yr x 12.28 yr = 319 kg Pu_{239} @ 60%	3 1/4 x 1-kT	40 x 1-kT
NAPS 1	220 MWe x 0.3 kg/MWe-yr x 0.446 FP = 29 kg/yr x 6.49 yr = 188 kg Pu_{239} @ 60%	3 1/2 x 1-kT	23 x 1-kT
NAPS 2	220 MWe x 0.3 kg/MWe-yr x 0.566 FP = 37 kg/yr x 6.00 yr = 222 kg Pu_{239} @ 60%	4 1/2 x 1-kT	28 x 1-kT
KAPS 1	220 MWe x 0.3 kg/MWe-yr x 0.489 FP = 32 kg/yr x 5.15 yr = 165 kg Pu_{239} @ 60%	4 x 1-kT	21 x 1-kT
KAPS 2	220 MWe x 0.3 kg/MWe-yr x 0.712 FP = 47 kg/yr x 2.83 yr = 133 kg Pu_{239} @ 60%	6 x 1-kT	17 x 1-kT
	257 kg/yr + 2,732 kg Total Pu_{239} @ 60%	= 32/yr + 342 Critical Masses	
	295 kg/yr + 3,299 kg Total Pu_{239}	= 39 1/2/yr + 455 Critical Masses	

I Steer/0037231

By far the bulk of India's plutonium has been created in its 10 nuclear power reactors. However, as Colin Hunt of the CNA points out: "So far as is known, India's power reactors have not been used to produce weapons-grade plutonium, and none of the reactor-grade plutonium they have produced has been diverted for weapons purposes."

Assuming they are slow-fuelled, India's eight CANDUs each produce around 0.3kg/MWe-yr of reactor-grade plutonium. The CNA provided actual FP performance histories for each reactor. The Rajasthan Atomic Power Station (RAPS) Unit One went into full power operation in 1973: one year before India's 1974 nuclear test. Following that test, further Canadian assistance was cut off. India nonetheless independently completed RAPS Unit Two, then under construction, by 1981. Both RAPS units, and their spent fuel, are under International Atomic Energy Agency (IAEA) safeguards. Their plutonium cannot be diverted for weapons. Since RAPS however, six more CANDU reactors have been built, all indigenously. None of these are safeguarded.

Two reactors went into operation at the Madaras APS: MAPS 1 in 1984 and MAPS 2 in 1986. Two more started up at Narora: NAPS 1 and 2, both in 1992. In 1993 and 1995 respectively, another two came on line at Kakrapar. All six indigenously built CANDU reactors have operated over their lifetimes at close to 50 per cent FP with one exception. KAPS Unit Two, India's newest, has run at 71.2 per cent for its first three years.

Two US-supplied Boiling Water Reactors have operated at the Tarapur APS (TAPS) since 1967 and 1968 respectively. Each produces around 0.09kg/MWe-yr of reactor-grade plutonium. Both are under IAEA safeguards. IAEA data on TAPS 1 and 2, published by Nuclear Engineering International (NEI), shows their respective time at FP has been 47.9 and 48.4 per cent.

India has a uranium enrichment plant at Ratnahally. The uranium produced there however, is probably not for weapons but for use as fuel in India's planned nuclear-powered submarine (see *JIR*, July 1998, pp 23-25).

Pakistan's critical masses

Plutonium production in the Pakistan Atomic Research Reactor (PARR) is unknown. Pakistan's only power reactor at the Karachi Nuclear Power Plant (KANUPP), a CANDU running since 1973, produces about 0.3kg/MWe-yr of reactor-grade plutonium, like India's CANDUs. Under IAEA safeguards, KANUPP's plutonium has not been used for weapons. Not IAEA safeguarded, however, is a new 17MWe plutonium production reactor completed in April at Khushab, probably with Chinese assistance. A Chinese-built 9kWe Miniature Neutron Source Reactor (MNSR) has operated for some time. Within a few years, Khushab will allow Pakistan to build plutonium-based atom bombs. Pakistan's nuclear weapons now use highly enriched uranium. Weapons-grade uranium 235 is being produced at a pilot-scale uranium enrichment plant operating since 1971 at Sihala and at a larger production facility operating since 1981 at Kahuta.

Most of what is known about these plants was originally revealed by the BBC in 1980 in a report on the weekly current affairs TV series *Panorama* and in a documentary entitled 'Project 706 – The Islamic Bomb' (see *The Islamic Bomb*, by Steve Weissman and Herbert Krosney, 1981), prescient enough then to be informative now. For example, Sihala's production capacity was revealed to be sufficient for three atomic bombs, or 45kg of uranium 235, per year. The reporters even got a rough but 'reasonable' estimate for the plant's operating efficiency. Actual output is around a third of the plant's maximum, or 33 per cent.

Kahuta, still under construction when the BBC reports aired, was stated to have a design capacity of 10,000 gas centrifuges. Data in 1992's Nuclear India, by V K Nair, revealed that each 1,000 centrifuges allow Pakistan to produce 21kg of uranium 235 per year. In addition, Kahuta was reported to have begun production in 1981: one year after the BBC reports. Initially, only 2,000 of its 10,000 centrifuges were installed. Two thousand more were being added every few to several years, with full operating capacity to be reached in the mid-1990s.

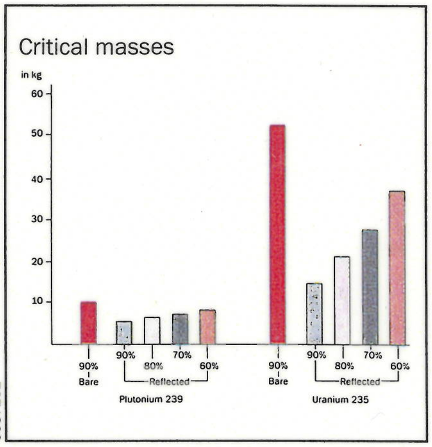
Assuming all 10,000 centrifuges are now installed and operating at 33 per cent of their capacity, Kahuta is producing 70kg of uranium 235, or enough for almost five atomic bombs, every year. ISIS also estimates five bombs per year from Kahuta (see *Scientific American*, August 1998, pp 16-17), although the Institute assumes five bombs at 20kg, or one-and-a-third critical masses each, and that Kahuta is producing 110kg of uranium 235 a year.

If it has operated for 17 years with an average of half its centrifuges installed (5,000), all running at 33 per cent, Kahuta will have produced 595kg of uranium 235 to date. This estimate is comfortably surrounded by ISIS's figures of between 500 and 700kg from Kahuta. Uncertainty exists due to the status of Pakistan's moratorium, self-imposed in 1991, against enriching uranium 235 beyond 20 per cent – far less than weapons-grade. Well intentioned, it would still allow Pakistan, by further enriching the partially enriched uranium produced, to make 'almost as much weapon-grade uranium as if no moratorium occurred'.

Weaponisation

India's plutonium can only be manufactured into weapons if it has first been separated from the spent reactor fuel in which it was created. India operates three plutonium reprocessing plants which, combined, have the capacity to seperate 500kg of plutonium a year. Unless these plants have continued to be built to sit idle, it is probable that a significant portion of India's plutonium has already been recovered and is readily accessible.

Certainly none of the 790kg in spent fuel from RAPS, under IAEA safeguards, has been recovered for weapons. The other



0037232

1,942kg that are un-safeguarded, however, may well have been recovered because India desperately needs plutonium for the second phase of its nuclear power programme, which is based on plutonium-fuelled reactors (see *JIR*, January 1998, pp 29-31).

Of course, it is probably true that none of India's reactor-grade plutonium has been diverted for weapons purposes, if for no other reason than it is far more valuable as an energy source than it is for weapons. It should be remembered however, that if India's un-safeguarded reactor-grade plutonium is accessible, it can be converted into 243 atomic bombs very quickly.

Only 624 hours of assembly were required for each Mk 3 atom bomb, based on 'Fat Man', 50 of which were hand-made at Los Alamos National Laboratory following the Second World War. Around 1500 hours may be required to assemble currently deployed US nuclear weapons.

Assuming India's nuclear weapons require, say, 1,000 hours of assembly and that much again to manufacture the components, it probably takes no more than 2,000 hours, or roughly one person one year, to construct one atomic bomb. Therefore, if India chose at some time in the future to transform 200 critical masses worth of its plutonium into that many bombs, it could probably do so with as few as 200 people in as little as a year. With 10 times that staff, this level of weaponisation could conceivably be achieved in just over a month.

Pakistan's inventory of highly enriched uranium is an even more immediate threat for weaponisation. Uranium 235, unlike plutonium, does not require reprocessing to be manufactured into warheads. It is hard to imagine that the nuclear weapon manufacturing plant at Wah, near Islamabad, has been sitting idly by while 67 critical masses worth of uranium 235 are awaiting assembly into atomic bombs.

Conclusion

Total weapons-grade critical masses manufactured to date probably stands at 113 for India versus 67 for Pakistan. Of this, perhaps 87 in India and 62 in Pakistan are available for deployment. This assumes that both countries used three critical masses in six nuclear tests each to date (most experts assume full, rather than subcritical, masses were tested, meaning six critical masses may have been used), that three critical masses in India and two in Pakistan have been lost in normal (3 per cent) production losses and that 20 critical masses in India have been used in nuclear reactor fuel for Purnima and the FBTR.

With so many weapons-grade critical masses already in the region, the threat of another 342 critical masses in India and 38 in Pakistan of non-weapons-grade materials being weaponised has to be taken seriously. What will the region's leaders conclude? 'Hawks' will point with alarm, not just to reactor-grade plutonium, but to the power reactors producing it. For example, in the worst future case, either country could kick out the IAEA and run its power reactors for maximum weapons production.

Fast-fuelling its 10 power reactors at current operating levels, India could produce enough weapons-grade plutonium over the next 10 years for at least 800 20kT atomic bombs. Added to its current inventory, along with additional materials produced by then in its research reactors, India could in theory have well over 1,000 atomic bombs by the year 2008. This does not include additional critical masses produced by then in any of 10 new reactors now planned or under construction.

Pakistan, fast-fuelling its CANDU reactor at its operating rate, could produce 40 plutonium-based bombs over the next 10 years. Added to plutonium from Khushab by then and another 60 uranium bombs from its enrichment plants, plus its existing inventory, Pakistan could potentially have more than 200 atomic bombs by 2008.

Even now, the situation might already be less 'rosy' than this report estimates. Specifically, if all 17 known nuclear materials production facilities in India and all six in Pakistan were to cease operations starting now, both countries might already have one third more reactor-grade plutonium than suggested here. This report uses figures of 0.3 and 0.09kg/MWe-yr from CANDU and TAPS reactors – grossly simplified estimates derived from widely published sources (see *Nuclear Pakistan: atomic threat to South Asia*, by PB Sinha and RR Subramanian, 1980). Deeper analysis indicates actual plutonium output from these reactors might be 0.4 and 0.12kg/MWe-yr respectively (see

Plutonium and Highly Enriched Uranium 1996, World Inventories and Capabilities, by Dr David Albright, et al, 1997).

What about unknown facilities? For example, India's uranium enrichment plant at Ratnahally was widely unknown until *JIR*'s July report. New types of facility, such as uranium enrichment plants based on laser isotope separation, can be small and hard to detect, yet these could produce hundreds of bombs. "The greatest danger facing NPT [the nuclear Non-Proliferation Treaty] is new technologies not envisioned when the treaty was signed," according to Hunt. "It is now possible to make certain kinds of weapons proliferation extremely difficult to detect and prevent."

What about outside sources of weapon materials? For example, does Pakistan get its extensive nuclear assistance from China for free? Or has Pakistan's 200kg annual capacity plutonium reprocessing plant at Chasma, fully operational since 1981, used Chinese-supplied reactor fuel to produce, at say 33 per cent efficiency, 226 20kT atomic bombs, half of which might be Pakistan's?

Finally, the total number of critical masses in the region estimated here, at 455 for India versus 105 for Pakistan, is already sufficient, without being a third larger or added to by outside sources or unknown facilities, to at some time in the future using sophisticated weapons designs (with a tenth of a critical mass each) allow India and Pakistan to threaten each other with 4,550 versus 1,050 warheads.

Of even greater concern, every atomic warhead can be used as the trigger for a hydrogen bomb, which is technologically easier to produce than its atomic trigger. India is already pursuing this technology. Tritium, the primary material required for hydrogen bombs, is being produced at a pilot-scale plant near Bombay and a full-scale tritium production plant will soon enter service at MAPS (see *JIR*, January 1998, pp 29-31). Pakistan may also learn to extract tritium, as India did, from the heavy water used to moderate all CANDU reactors.

No one believes either country wants to become involved in such a nuclear build-up, except the hawks in either country. However, with the two countries' nuclear tests this year demonstrating that the hawks hold sway in south Asia, there is a risk. Just as the 'bomber gap' and 'missile gap' once led the USA and Soviet Union to further weaponisation, leaders in New Delhi and Islamabad may overestimate each other's nuclear capabilities, especially regarding power reactor plutonium. As a result, each may escalate their own capabilities accordingly. Nuclear escalation by both sides is already evident in their race for more and better ballistic missiles (see *JIR*, January 1998, pp 32-35).

According to Hunt: "The only way these countries can avoid fearing each other's nuclear capabilities is if they both sign the NPT and allow IAEA inspectors to verify for them that their power reactors at least are not a threat." ●

The number of critical masses of weapons-grade materials (in black) and reactor-grade plutonium (in red tint) in both India and Pakistan is greater than acknowledged.