India's Uranium Enrichment Program

■ M.V. Ramana

The last two years have seen revelations about secret uranium enrichment programs in Iran and South Korea. An older uranium enrichment program about which little is known publicly is India's. Details of uranium enrichment activities have been kept largely secret in India, even more so than its other nuclear activities.[1] Here I summarize what is known about the program, estimate its capacity and how much weapons-grade uranium could be produced at this facility should it be used to do so.

India's interest in uranium enrichment dates back to the early 1970s.[2] But it was only in 1986 that Indian Atomic Energy Commission Chairman Raja Ramanna announced that uranium had successfully been enriched.[3] According to one report, a pilot scale plant has been operating in the Bhabha Atomic Research Center complex since 1985.[4] A larger centrifuge plant has been reportedly operating at Rattehalli, Karnataka, since 1990.[5] This is India's main uranium enrichment facility. There is also an experimental laser enrichment program.

Construction of the Rattehalli plant started in the mid 1980s.[6] During the initial years of operation, the plant reportedly had "frequent breakdowns as a result of corrosion and failure of parts."[7] It is therefore not surprising that many leaders of the Indian Department of Atomic Energy (DAE) held that uranium enrichment was very difficult and were skeptical of Pakistani claims that they had succeeded in enriching uranium to weapons-grade levels. Indeed, at least one chairman of the Indian DAE has privately argued that Pakistan did not have a nuclear weapon capability because it could not have succeeded in enriching uranium to weapons-grade levels because of the difficulties in constructing centrifuges of the required capacities.

The Rattehalli Plant and the Nuclear Submarine Program

The primary purpose of the Rattehalli plant appears to be to enrich uranium for the Indian nuclear submarine, officially termed the Advanced Technology Vessel (ATV), program. It is also possible that enriched uranium from this facility was used in the hydrogen bomb tested on 11 May 1998.[8] Highly enriched uranium (HEU) is used in U.S. and Russian thermonuclear weapons.

According to a report from the early 1990s quoting unnamed official sources, the Rattehalli facility consists of "several hundred operating centrifuges made of domestically-produced maraging steel" with "a likely design throughput of under three separative work units (SWU) per machine per year."[9] One could take this to mean a total enrichment capacity of about 1,000-2,000 SWU/year. In 1997, it was reported that the DAE was planning to "build and install rotor assemblies of improved design."[10] Different enrichment levels for the output of the facility and the fuel used in the ATV submarine reactor have been reported these range from 6%-45%, but we will assume a range from 30-45%.

If, as Indian officials state, the primary purpose of the Rattehalli facility is to produce fuel for the ATV program, an analysis of the submarine reactor requirements could help estimate the uranium enrichment capacity.[11] Strictly speaking this would only provide a lower bound. However, since the program has had operating difficulties, it is quite likely that the actual capacity is reasonably close to this lower bound.

Despite relatively prolific coverage of the Indian nuclear submarine program in the media, there is considerable confusion about its technical characteristics. In part this reflects the fact that the program started over 25 years ago and has evolved considerably over the decades.[12] After numerous setbacks and failures, by the late 1990s a reactor design was finalized, and testing of a prototype commenced at the Kalpakkam nuclear complex in southern India.[13] This implies that between 1990 and the late 1990s, the Rattehalli complex should have produced at least sufficient enriched uranium to fabricate the reactor core.[14]

HEU for the Submarine Reactor

The amount of enriched uranium needed for a nuclear submarine reactor depends on a number of factors. These include the reactor power rating, the level of enrichment, the time intervals between core refuelings, the burn-up (which determines the fraction of the initial U-235 that is consumed before re-fueling [by conversion to U-236 as well as fission]), the reactor design (including factors such as fuel geometry, the use of burnable absorbers, and so on), and the use pattern (the average number of effective full power days per year or the average power the reactor produces through its lifetime). None of these are definitively known, and there are contradictory reports on some of these quantities (such as the power rating of the reactor).

One can set a lower bound on the power required by a submarine by estimating what is needed to overcome drag at the maximum design velocity. The maximum velocity of the ATV is usually given as about 30-35 knots, which corresponds well to maximum velocities reported for other nuclear submarines.[15] At the lower value of 30 knots (15 m/s), the ATV would take about 36 hours to go from Thiruvananthapuram, a likely site for India's strategic nuclear command center, to Karachi, Pakistan's chief port and a likely site of naval blockade by India in the event of a war.

Assuming this speed and reasonable values for the other physical variables, the reactor power needed is about 112 MWth. However, this estimate is sensitively dependent on the assumptions made about various quantities. Therefore, it may be safe to assume that the submarine reactor power is somewhere between 90 MWth and 150 MWth.

The amount of uranium that is required for the submarine reactor core to operate at this power level depends on the reactor design, the time between re-fuelings, as well as the operational procedures and patrol routines followed by the submarine. For the same power rating and time between re-fuelings, the uranium inventory for a submarine that has a more demanding patrol routine would be higher. The core of the ATV is reported to have a design lifetime of ten years.[16]

Estimates of the U-235 requirements for U.S. submarines are about 0.6-0.7 g/shp-year,[17] while the requirements for Russian submarines are likely to be about 0.315–0.35g/shp-year.[18] The propulsive power rating for Charlie Class submarines is 20,000 shp.[19] Similarly, the Sevmorput nuclear icebreaker/cargo ship requires about 0.375 g/shp-year of U-235.[20] Due to the smaller distances that the ATV is likely to traverse, one could assume that the ATV will require about 0.3 g/shp-year of U-235. Based on all these different assumptions, I estimate that the core of the ATV might use about 40-160 kg of U-235, with a median estimate of 90 kg. The actual amount of uranium used will also depend on the level of enrichment.

HEU for Nuclear Weapons

An additional demand for enriched uranium might be to test or manufacture thermonuclear weapons. In two-stage thermonuclear weapons, enriched uranium can be used in the primary, in the "spark plug" to aid in initiating the fusion reaction, or in the "pusher" encasing the fusion fuel.[21] Enriched uranium may also be used to replace the "blanket" surrounding the warhead, which is usually made of depleted uranium, so as to increase the yield of a thermonuclear weapon.[22] However, according to the official announcement that followed the 1998 tests, "the yield of the thermonuclear device tested on May 11 was designed to meet stringent criteria like containment of the explosion and least possible damage to building and structures in neighboring villages."[23]

If this were indeed the case, it is likely that the blanket may have been made of inert material. The requirement for enriched uranium may only be a few kilograms used in the spark plug in this case.[24] We will assume this figure to be 5 kg and that about 10 kg of U-235 was produced for the test carried out on 11 May 1998. Apart from the amount actually used in the device exploded, this would also include processing losses and material used for conducting laboratory experiments.

In this scenario, the Rattehalli plant should have produced at least 100 kg of U-235 by 1999 for the submarine core and the thermonuclear device tested on 11 March 1998. Depending on whether India decided to stockpile thermonuclear weapons, there may or may not be a continuing demand for enriched uranium for weapons.

Estimated Enrichment Capacity

Enrichment capacity is measured in Separative Work Units (SWU), or more precisely kilogram SWUs, and is the quantity of separative work (indicative of energy used in enrichment) when the quantities of the feed (usually natural uranium), the enriched product, and the remaining tails are expressed in kilograms. The enrichment capacity requirements, the feed requirements, and the amounts of uranium enriched to different levels containing 1 kg of U-235 are summarized in Table 1. For a given tails enrichment level, the SWU requirements per unit mass of U-235 does not depend strongly on the enrichment level. This SWU requirement may be lowered by using a higher enrichment level for the tail, but that would significantly increase the amount of uranium used as feedstock. We therefore assume that the tails enrichment level is 0.3%, which means that that it would take approximately 200 kgSWU to produce a kilogram of U-235. Thus, manufacturing the 90 kg submarine core would require 18,000 kgSWU of enrichment capacity. A 40 kg core would require 8,000 kgSWU of enrichment capacity and a 160 kg core would require 32,000 kgSWU of enrichment capacity.

Based on reasonable assumptions about when enrichment started and the tail enrichment level, our estimates of enrichment capacity are listed in Table 2. The best estimate of current (2004) capacity from our analysis is 4,800 kgSWU/year. However, we emphasize that there are significant uncertainties and so it would be more reasonable to quote a range of enrichment capacities, namely 3,900-10,400 kgSWU/year. The amount of enriched product produced would depend on the enrichment level. For example, if the facility were producing weapons-grade uranium (93% enrichment), then with this range of capacities, the

Enrichment	Tails	SWU/kg	Kg-EU/ kg-U-235	kgSWU/ kg-U-235	kg-feed*/ kg-U-235
30	0.3	59.8	3.3	199.3	240.9
40	0.3	81.5	2.5	203.7	241.5
45	0.3	92.4	2.2	205.3	241.7
40	0.2	96.6	2.5	241.5	194.7
40	0.5	64.4	2.5	161.0	468.0

*Feed is assumed to be natural uranium.

Table 1: SWU Requirements

Requirements	Average enrichment capacity (1991-1999)	Enrichment capacity in 1999*	Current enrichment capacity (2004)*
Submarine core (90 kg U-235)	2,250 kgSWU/y	3,000 kgSWU/y	3,900 kgSWU/y
Submarine core (160 kg U-235)	4,000 kgSWU/y	6,500 kgSWU/y	9,600 kgSWU/y
90 kg submarine core + 1998 thermonuclear test (10 kg U-235)	2,500 kgSWU/y	3,500 kgSWU/y	4,800 kgSWU/y
160 kg submarine core + 1998 thermonuclear test (10 kg U-235)	4,250 kgSWU/y	7,000 kgSWU/y	10,400 kgSWU/y

*assuming linearly increasing capacity and rounded off

Table 2: Estimates of enrichment capacity

facility could produce about 20-50 kg every year. If the facility were producing 30-45% enriched uranium, then it could produce about 40-175 kg of enriched product and 4,500-12,400 kg of depleted uranium every year.

There is no indication that India is seeking to fuel any of its Light Water Reactors with indigenous enriched uranium. This is also borne out by the above estimates of the capacity. A facility with a capacity of about 10,000 kgSWU/year could produce about 2.6 tons of 3.3% enriched uranium each year. This is to be compared with the initial core loading of 66 tons for the VVER-1000 reactors that India is importing from Russia.[25] Thus, at the estimated range of current capacities, it would take decades for India to enrich sufficient uranium for even one reactor core.

This estimate of enrichment capacity also has implications for the size of the nuclear submarine fleet that can be sustained by India. At 200 kgSWU/kg-U-235 and 90 kg U-235/reactor core, a 4,800 SWU/year facility could produce a reactor core in about four years. Nuclear strategists have argued that India requires a fleet of three to five submarines.[26] Since each submarine would need a new core in ten years, the estimated current capacity may be just insufficient to produce the enriched uranium requirements for a three submarine fleet. But since the enrichment capacity can be increased, this may not be a major bottleneck.

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1 For example, the location of the uranium enrichment plant was not included in the list of nuclear sites exchanged by the governments of India and Pakistan as a confidence building measure, Hibbs, 1992a.
2 Albright et al., 1997, pp. 269-270.
3 Chellaney, 1987.
4 Fera and Srinivasan, 1986.
5 Hibbs, 1992b.
6 Fera and Srinivasan, 1986.
7 Albright et al., 1997, pp. 270.
8 Though the yield of the nuclear test and therefore the success of the design have been questioned, there is no reason to doubt official Indian assertions that a two-stage thermonuclear bomb was tested.
9 Hibbs, 1992b.
10 Hibbs, 1997.
11 For a more detailed analysis of these requirements see Ramana, 2004.
12 For a useful history of the program see Rethinaraj, 1998.
13 Raghuvanshi, 2001; Kumar, 1998; Gopalakrishnan, 2000. One report claims that these tests are of a "scaled down reactor" but this has not been corroborated elsewhere. Even if true, it is still likely that the Rattehalli

complex would have produced sufficient enriched uranium to fabricate the entire reactor core.

14 It is of course possible that the necessary enriched uranium was produced much earlier. But the reports that the Rattehalli facility was not working well suggests that the necessary enriched uranium would have likely been produced only close to the time the reactor began to be tested.

15 See for example Raghuvanshi, 2001.

16 Anonymous, 1999.

17 von Hippel et al., 1986. shp = shaft horsepower; 1 shp = 0,746 kilowatts.

18 My calculations based on information from Podvig, 2001, pp. 273-278, Bukharin, 1996, and Nilsen et al., 1996.

19 FAS, Undated.

20 My calculations based on information from Mærli, 1998 and Ølgaard, Undated.

21 Hansen, 1995, pp. I-94. The spark plug is a fissile mass placed in the center of the fusion fuel. When the fusion fuel is compressed by the shock wave, the fissile mass is compressed to supercritical densities setting off a chain reaction, which increases the yield and produces additional neutrons that could induce ignition of the secondary.

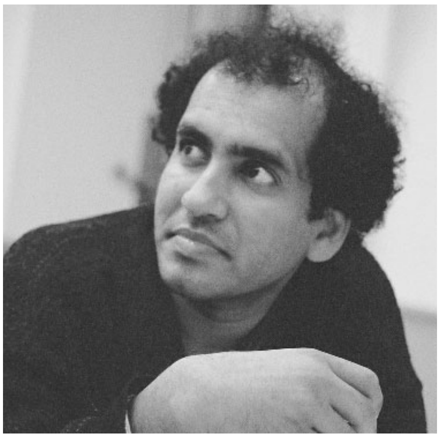
22 Alvarez and Sherman, 1985.

23 DAE and DRDO, 1998.

24 This would presumably increase the chances of igniting the secondary, a likely goal for a first thermonuclear test.

25 Nuclear Engineering International, 1998, pp. 60. VVER = Voda-Vodyanoi Energiticheskiy Reaktor, the Russian pressurized water reactor.

26 Reddy, 2003, pp. 380-381.



M.V. Ramana is Fellow at the Centre for Interdisciplinary Studies in Environment and Development, ISEC Campus, Nagarabhavi, Bangalore 560072, India; tel. +91-80 23 21 70 13 (X24); ramana@isec.ac.in; http://www.cised.org.

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Another Nuclear White Elephant

■ Zia Mian and A.H. Nayyar

Bearing in mind the fact that the Chashma-I nuclear power plant has proved nothing to write home about, there seems to be little justification for the Chashma-2 project. Are all things nuclear above the law?

Pakistan has signed up to buy its second Chinese-made nuclear power plant. This new plant will be identical to the earlier reactor at Chashma, designed and built by the Chinese, on the banks of the Indus River, about 30 miles from Mianwali. The project has been given the go-ahead despite the fact that the experience with the first reactor has not been encouraging. Economic factors related to the project are dubious and many questions that were raised about the safety of the Chinese design and the location of the first reactor at Chashma remain unanswered.

The deal for the Chashma-2 nuclear power plant was signed in May this year. It is said that the reactor will be built in less than seven years, with some reports suggesting it might start operating by 2010. But building a nuclear power plant is no simple matter. There were similar claims about the Chashma-1 plant. When the Chashma-1 contract was signed at the end of 1991, it was thought that the reactor would start operating in six years. But it took almost nine years before it was finally handed over by the Chinese to the Pakistan Atomic Energy Commission (PAEC) in late 2000, and it was only formally inaugurated in early 2001. It is quite likely that the schedule for Chashma-2 will slip too, and it may be closer to 2015 before the reactor starts producing electricity.

Economics factors related to nuclear electricity are quite mysterious in Pakistan, since the PAEC cloaks itself in secrecy and seems reluctant to give away any kind of detailed accounts. But it was reported that the Chashma-1 reactor cost somewhere between US$ 600 million and over US$ 1 billion. Some informed sources suggest the actual cost was about US$ 1.3 billion, that is, approximately double the cost that was originally claimed. This is a staggering figure considering that the plant was designed to produce only 300 MW, meaning over US$ 4 per MW of electrical power capacity. For comparison, this is more than twice the cost for every megawatt of electricity generating capacity from the Ghazi Barotha hydroelectric project inaugurated by President Musharraf in August 2003. It has been reported that Pakistan has budgeted Rs 54.392 billion for the Chashma-2 reactor. As with Chashma-1, the actual final cost is likely to be higher.

The operating costs of nuclear reactors (per unit energy produced) are invariably higher than those of a thermal power plant. This is true in Pakistan's case. Thus the electricity produced by nuclear power plants is bound to be costlier.

While China designed and built the Chashma-1 project, which the PAEC now operates, it is Wapda that has to buy electricity (to distribute it for domestic use etc). In 2003, Wapda complained publicly that it was being forced to pay almost twice what it should for electricity generated through Chashma-1. The electricity that Wapda produces and buys from independent power producers is much cheaper than what is being charged by the PAEC for Chashma-1. The dispute over price between them was eventually settled after the government intervened and forced Wapda to pay some extra amount. Wapda officials have argued that this is causing them an annual loss of Rs 3 billion. One senior official is of the view that the Chashma-1 plant is "going to eat our revenues for decades." There is no reason to expect that electricity generated by Chashma-2 will be any cheaper. But whatever the cost