India's Military Plutonium Inventory, End 2004

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Estimating the size of India's inventory of separated weapon-grade plutonium has become more difficult following its nuclear tests in May 1998. India treats this number as highly classified, partly because such estimates provide a direct indication of the number of nuclear weapons it may possess. The purpose of this report is to summarize estimates of its stock of weapon-grade plutonium. A companion report discusses India's highly enriched uranium stock.

Production Complex

At the core of India's production of plutonium for nuclear weapons are two relatively small heavy water-moderated reactors and a plutonium separation plant at the Bhabha Atomic Energy Center (BARC) in Mumbai. The two reactors use natural uranium metal fuel and produce weapon-grade plutonium. The uranium metal fuel for these reactors is also produced at BARC.

Cirus Reactor

The 40 megawatt-thermal (MWth) Cirus reactor first went critical in 1960. This reactor, which was supplied by Canada, operated until 1997 when it shut down for major renovations because of aging problems. India considered building a new reactor to replace Cirus, but decided against that option for cost reasons.

After extensive modification, the reactor restarted in October 2003 and reached full power in November 2004. Indian officials expect Cirus to last for about 15 more years.

Dhruva Reactor

The 100 MWth Dhruva reactor, which was developed indigenously, went critical in August 1985. Soon after starting operation, the reactor experienced severe vibrations in the reactor core and was shut down for modifications. In December 1986, it resumed operation at quarter power. In January 1988, the vibration problem was solved and the reactor attained full power.

Trombay Plutonium Separation Plant

India started the Trombay plutonium separation plant in 1964 to reprocess irradiated fuel from the Cirus reactor. It was shut down in 1974 for renovation and expansion and restarted in 1983 or 1984. After renovation, Trombay was able to process fuel from both the Cirus and Dhruva reactors. While this plant was closed, Cirus' irradiated fuel was processed at the Prefre reprocessing plant north of Mumbai that began operation in 1979.

Candu Power Reactors

Most of India's Candu power reactors are not safeguarded by the International Atomic Energy Agency (IAEA) and are not committed to peaceful uses by international treaties or agreements. However, India does not appear to plan to use these reactors to produce plutonium for nuclear weapons. To operate a Candu reactor in a mode to make weapon-grade plutonium, India would need to produce a much greater amount of fuel. India's Prefre and Kalpakkam Candu fuel reprocessing plants would also need to work significantly more reliably and process considerably more irradiated fuel than they have done so far. Indian officials have also expressed concern about international reaction to such a step.

Nonetheless, suspicions remain that India may have used some of the plutonium produced in its Candu power reactors in its nuclear weapons program. The most likely candidate would be plutonium in low-burnup initial fuel discharges from these reactors.

Plutonium Estimates Through the End of 2004

Since the 1998 nuclear tests, India is believed to have invested more resources into increasing its inventory of weapon-grade plutonium. Its focus appears to be on increasing the plutonium output of the Cirus and Dhruva reactors. Toward that end, BARC expanded its capacity to make uranium metal from uranium tetrafluoride to ensure adequate fuel for the Dhruva reactor and a renovated Cirus reactor.

An estimate of India's military plutonium stock is composed of two basic assessments. The first involves calculating the total amount of plutonium produced in the Cirus and Dhruva reactors. A part of this assessment is accounting for any plutonium from Candu power reactors assigned to the military program. The second assessment involves determining the amount of plutonium produced in these reactors that has been consumed or used for non-military purposes. It is assumed that almost all of the plutonium is successfully recovered during reprocessing.

Any estimate of India's weapon-grade plutonium inventory remains highly uncertain. Complicating any estimate is the mixture of solid and ambiguous information regarding India's capabilities and actions. As a result, an analytical approach is used that specifically aims to capture varying and conflicting information about key parameters affecting estimates of the size of India's plutonium stock. Rather than decide on a best estimate for a specific parameter, such as lifetime reactor operating capacity, a frequency distribution of possible values is derived.

Using Crystal Ball® software, distributions representing key parameters in a formula are sampled using a Monte Carlo approach to derive a distribution of results. This method varies from earlier approaches used by the author, where central or best estimates are derived, and an uncertainty is attached by making a judgment about the overall data and information.[1] Although judgments are still necessary in any uncertainty analysis, they can be applied in a more transparent manner with this software.

Total Plutonium Production

The formula used to estimate the total amount of weapon-grade plutonium produced in the Cirus or Dhruva reactors is straightforward:

Total Plutonium = Power x Capacity Factor x Years in Operation x Plutonium Conversion Factor,

where the last factor is the amount of weapon-grade plutonium in the discharged fuel per unit of energy produced per tonne of uranium in the fuel.

The most critical parameter in estimating the total amount of plutonium produced by one of these reactors is its capacity factor, which is defined here as the energy produced divided by the amount theoretically possible to produce in a year. Estimates of the capacity factors of these reactors vary widely.

Indian officials state that the reactors achieved a capacity factor of 60 to 70 percent over long periods of time. Indian senior nuclear officials stated in interviews in 1992 that the annual capacity factor of the Dhruva reactor was 60-65 percent. Indian officials also state that Cirus achieved a capacity of 70 percent until 1990, after which the capacity factor decreased because of aging problems in the reactor. One report stated that the reactor after 1990 was de-rated to a power of 20 MWth, implying a capacity factor of less than 50 percent during this period.

These statements cannot be confirmed and interpreting them is difficult. Dhruva had a capacity factor less than 25 percent during its first few years of operation. Other problems may have developed in the reactor that lowered its lifetime capacity factor below 60-65 percent. Indian officials may be giving capacity factors for periods when the reactors operated well and ignoring periods when the reactors were shut down or operating at significantly reduced power. This practice is rather common when discussing nuclear power reactors. In this case, a capacity factor of 60-65 percent would more likely be a maximum lifetime capacity factor.

Such an interpretation is supported by statements from US government experts. In the late 1990s, knowledgeable experts from US national laboratories stated in briefings and interviews that the Cirus and Dhruva reactors had achieved a lifetime capacity factor of only about 40 percent. These estimates were widely circulated at the time, but their reliability could not be ascertained.

[1] See for example, David Albright, Frans Berkhout, and William Walker, *Plutonium and Highly Enriched Uranium 1996* (Oxford: SIPRI and Oxford University Press, 1997).

This study could not reconcile these different values, although the Indian statements are believed to be overestimates of lifetime capacity factors. On the other hand, the US information may be underestimating the true values.

With regard to the Cirus reactor, the lifetime capacity factor, covering the period from startup in 1960 until shutdown in 1997, is estimated as a triangular distribution in the Crystal Ball® calculations, with the most likely value as 50 percent and the minimum and maximum values as 30 and 70 percent, respectively. This choice tends to weight the US information more than the Indian information. At the same time, the Indian information is included in the resulting estimate of total plutonium production. The relatively small amount of plutonium produced since Cirus restarted in late 2003 is ignored in this estimate.

The capacity factor for the Dhruva reactor is estimated for two different periods. The first period stretches from 1985 through 1998, and the second period is from 1998 through 2004. The reason for developing estimates for two different periods is that whatever the true situation, after the tests in 1998, India likely improved operations at the Dhruva reactor to further increase its supply of weapon-grade plutonium. The capacity factor for the first period is represented as a triangular distribution with the most likely value as 40 percent and the minimum and maximum values as 30 and 60 percent, respectively. The estimate accepts the US experts' assessments of the relatively low capacity factor through the late 1990s. For the second period, the multi-year capacity factor is represented as a uniform distribution with a minimum of 55 percent and a maximum of 75 percent. In this distribution, any value between 55 and 75 percent has an equal chance of being sampled in the Monte Carlo calculation. This choice reflects a judgment that the Dhruva reactor has operated consistently better after the 1998 tests.

The amount of plutonium from power reactors assigned to the military program is believed to be relatively small. This source of plutonium is represented in the calculations as a triangular distribution with a most likely value of 35 kilograms, a minimum of 10 kilograms of plutonium, and a maximum of 60 kilograms.

The calculation for total plutonium production for the military program through 2004 gives a median value of about 575 kilograms of weapon-grade plutonium. The range is defined as all values between the 5^{th} and 95^{th} percentiles, which are 495 and 665 kilograms, respectively. One way to interpret the results is that there is a 90 percent certainty that the true value lies between 360 and 530 kilograms of weapon-grade plutonium, where the median value is about 450 kilograms.

Draw Downs

Some of the plutonium produced in the Cirus and Dhruva reactors has been used in nuclear tests, lost in processing, or assigned to civil fuel. These quantities must be subtracted to derive the net plutonium stock. The largest overall users of plutonium from these reactors have been civil reactors utilizing plutonium fuels, including the Fast

Breeder Test reactor (FBTR), the Purnima reactor, the Zerlina reactor, and power reactors. Nuclear testing in 1974 and 1998 also used a portion of this plutonium.

As above, many of these draw downs had to be estimated and are represented by ranges in the calculation. The calculation for the total amount of draw downs has a median of about 130 kilograms and 5^{th} and 95^{th} percentiles of 110 and 150 kilograms, respectively.

Net Plutonium Inventory, End of 2004

The net military inventory is the total amount of plutonium produced minus the amount of plutonium used in nuclear testing, lost during processing, and assigned to civil uses. At the end of 2004, the median value of the estimate of this inventory is 445 kilograms of plutonium, and the 5^{th} and 95^{th} percentiles are 360 and 530 kilograms, respectively.

For comparison, the estimate of the net military plutonium inventory through 2003 had a median value of 425 kilograms and 5^{th} and 95^{th} percentiles of 345 kilograms and 510 kilograms, respectively.[2] The increase in 2004 was thus about 20 kilograms of plutonium.

Estimated Equivalent Number of Nuclear Weapons, End of 2004

Estimates of the number of Indian nuclear weapons are highly uncertain. Media and government sources continue to suggest that India has not built as many nuclear weapons as it could, given its inventory of weapon-grade plutonium. Nonetheless, India has likely used the bulk of its plutonium to make nuclear weapons.

As a result, an upper bound estimate of India's nuclear arsenal at the end of 2004 can be derived from its estimated stock of weapon-grade plutonium. In this estimate, the amount of plutonium needed for a nuclear weapon is represented by a triangular distribution that varies from 4 to 7 kilograms with the most likely value as 5 kilograms. The median value is about 85 weapons, and the 5^{th} and 95^{th} percentiles are about 65 and 110 weapons, respectively.

[2] These estimates for the end of 2003 are greater than estimates made by the author in 2004. The median of the distribution for the net amount of plutonium at the end of 2003 in this study is about 45 kilograms greater than last year's median for this amount. The reason for the increase is because this year's estimate assigns higher capacity factors to the Cirus reactor throughout its lifetime and to the Dhruva reactor after 1998.