Chinese Military Plutonium and Highly Enriched Uranium Inventories

By David Albright and Corey Hinderstein

ISIS

June 30, 2005

Although considerable amounts of information have emerged about the Chinese nuclear weapon program during the last 20 years, great uncertainty surrounds plutonium and highly enriched uranium (HEU) stocks.[1] Little information has become available since *Plutonium and Highly Enriched Uranium 1996* was published.[2] Further complicating any analysis, China still treats details about a key plutonium production reactor and an enrichment plant as secret.

Unlike the other declared nuclear weapon states, China has yet to officially state that its production of fissile materials for weapons has ended. However, unofficial Chinese statements indicate that such production ended by about 1991. In February 1997, for example, a senior Chinese official confirmed to the authors that production of fissile material for nuclear weapons in China had ceased. He further indicated that China did not plan to announce that publicly. He did not discuss whether any steps were being taken to dismantle the fissile material production infrastructure in China or limit China's ability to restart production.

Chinese officials have stated for almost two decades that operations at its military nuclear production facilities were being scaled back in order to concentrate on civilian nuclear power. In 1994, for example, Jiang Xinxiong, then-general manager of the China National Nuclear Corporation, said that "most of the nuclear factories are closed or have stopped operation."[3] He added: "Military production has been reduced to the minimum - on State orders, and development of nuclear electric power is our main task." Despite such statements, the status and operational history of Chinese production reactors and enrichment plants remain shrouded in mystery.

---

[1] The main sources on China overall nuclear weapons program are J. W. Lewis and L. Xue, *China Builds the Bomb* (Stanford University Press: Stanford, Calif., 1988); W. Lewis and L. Xue, "Chinese Strategic Weapons and the Plutonium Option," *Critical Technologies Newsletter* (US Department of Energy: Washington, DC, April-May 1988); *China Today: Nuclear Industry*, April 1987. Selections translated by the Foreign Broadcast Information Service, JPRS-CST-88-002, 15 January 1988; and JPRS-CST-88-008, Washington, DC, April 26, 1988; and R. S. Norris, A. S. Burrows, and R. W. Fieldhouse, Natural Resources Defense Council, *Nuclear Weapons Databook, Vol V: British, French, and Chinese Nuclear Weapons* (Westview Press: Washington, DC, Mar. 1991).

[2] David Albright, Frans Berkhout, and William Walker, *Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities, and Policies* (Oxford University Press: Oxford,1997). This report draws heavily upon information on China in this book.

[3] Lorien Holland, "China Plans to Demilitarize Nuclear Industry," United Press International, September 26, 1994.

Highly Enriched Uranium Stock

Public knowledge about Chinese HEU stocks is limited. Unlike other nuclear weapon states, China has not published any information about the size of its HEU stock or production data about its HEU facilities.

Faced with a large HEU stock and the need to develop civilian nuclear power, China is reported to have stopped producing weapon-grade uranium for weapons in 1987.[4] *Nuclear Fuel* reported on May 17, 1999 that US officials, quoting intelligence officials, stated that they are satisfied that China has not resumed HEU production. Current information supports this 1999 assessment.

Gaseous-diffusion plants

As a result of Soviet-Chinese collaboration in the 1950s, the Soviet Union assisted China in the initial construction of a gaseous-diffusion enrichment plant at Lanzhou located in the Gansu province (central China) on the Yellow river.[5] Construction started in 1957, but a rift between China and the Soviet Union led to the withdrawal of all Soviet aid by mid-1960. Nevertheless, China received a significant amount of the necessary technology and components for a gaseous-diffusion plant.[6] This included some of the diffusers (with separation membranes), or separation equipment, and much of the specialized equipment necessary to monitor and run the plant. Reports state that Russia provided these items from its first gaseous diffusion plant, the D-1, at Verkh Neyvinsk.[7]

China faced a daunting task, however, in finishing the plant. Only on January 14, 1964 did the Lanzhou plant start producing weapon-grade uranium.

The equipment in the D-1 plant was inefficient and of inferior quality compared to the equipment in the follow-on Russian gaseous diffusion plants. The Chinese encountered problems in learning to use and duplicate the Soviet-supplied components and in manufacturing missing equipment. China also had to quickly develop the capability to make uranium hexafluoride, since the original plan had called for Russia to provide the initial requirements. These challenges delayed both the opening of the plant and its expansion.

---

[4] Ann MacLachlan, and Mark Hibbs, "China Stops Production of Military Fuel: All SWU Capacity Now for Civil Use," *Nuclear Fuel*, November 13, 1989. The 1987 data are from a personal communication to one of the authors of this report from Hibbs, who was told this by the head of the China Nuclear Energy Industry Corporation.

[5] The description of the Chinese development of gaseous diffusion plants is based on *China Today*, op. cit.

[6] *China Today*, op. cit.

[7] Heinz Barwich, a captured German scientist who worked in the early Russian gaseous-diffusion program, and then settled in East Germany before defecting to the West in 1964, told Gernot Zippe that the first Russian gaseous diffusion plant, namely D-1, was dismantled and sent to China in the late 1950s, personal communication from Zippe to one of the authors of this report. However, *China Today: Nuclear Industry* states that not all the auxiliary equipment was delivered [Part II, p. 51 in translation].

US intelligence agencies thought as late as August 1964 that the Lanzhou uranium enrichment plant was incomplete.[8] At that time the CIA believed that "on balance" China would not have enough fissile material for a test until after the end of 1964.[9] Thus, the United States was surprised when China tested its first nuclear explosive on October 16, 1964 using HEU produced in the Lanzhou plant.

Despite a wealth of information about the construction and upgrading of the plant, no official information exists on the capacity of the plant during the mid-1960s or later. Its initial nominal capacity is estimated at between 10,000 and 50,000 separative work units (SWU) per year, based on knowledge about early Soviet enrichment plants. At this capacity, the plant could have produced about 60-300 kg of weapon-grade uranium each year at a tails assay of 0.5 per cent. Despite needing a large stock of natural uranium at this tails assay, China may have picked a high tails assay to reduce the amount of SWU needed to produce each kilogram of HEU. Later, China likely would have used a lower tails assay.

In 1972, the US Defense Intelligence Agency (DIA) estimated that the Lanzhou facility was producing weapon-grade uranium at an estimated rate of 150-330 kg per year.[10] At a tails assay of 0.5 per cent, this rate is equivalent to 24,000-53,000 SWU per year. At a tails assay of 0.3 per cent, the plant would produce the equivalent of 30,000-66,000 SWU per year.

The first major increase in capacity occurred in the mid-1970s, when the separation equipment in the plant was improved.[11] It was reported in 1978 that the plant's capacity was 180,000 SWU per year.[12] This value appears high based on the description of the plant in *China Today: Nuclear Industry*.

A second period of expansion of the plant occurred during the early 1980s, when China achieved an "enormous breakthrough in separation membrane technology."[13] This development led to a further increase in separation efficiency. These improvements during the 1970s and 1980s resulted in a "many-fold" increase in production capacity over initial output.[14] Afterwards, the plant is reported to have reached a capacity of about 300,000 SWU per year.[15] Figure 1 shows a recent image of the Lanzhou enrichment plant.

---

[8] Director of Special Intelligence, "The Chances of an Imminent Communist Chinese Nuclear Explosion", Special National Intelligence Estimate, 13-4-64, August 26, 1964, declassified version in K. C. Ruffner (ed.), *CIA Cold War Records: America's First Satellite Program* (CIA Center for the Study of Intelligence: Washington, DC, 1995).
[9] Ibid.
[10] US Defense Intelligence Agency, *Soviet and Peoples' Republic of China Nuclear Weapons Employment Policy and Strategy*, TCS-654775-72, Mar. 1972.
[11] *China Today*, op cit.
[12] "Mainland China Talking to French, Germans, about Nuclear Power," Nucleonics Week, January 12, 1978.
[13] *China Today*, op. cit., p. 14, in translation.
[14] *China Today*, op. cit., p. 15, in translation.
[15] "China Stops Production of Military Fuel," op. cit.

China has a second, larger gaseous-diffusion plant at Heping (sometimes Heiping) in Sichuan, although details of it are sketchy, including its size and its operational status. Figure 2 is believed to be a recent commercial satellite image of this site.

China officially does not admit to the existence of this enrichment facility, further complicating any analysis of its HEU output. The plant is believed to have started operating in about 1975 and to have been built as a "third-line" weapon manufacturing site.[16] Starting in 1964, the Chinese leadership ordered the construction of strategic facilities in the interior of the country, far from the more vulnerable coasts and borders. This pattern was also followed in the case of plutonium production.

In 1972, about three to four years before the plant started operating, the Defense Intelligence Agency estimated that this plant would be capable of producing 750-2950 kg of weapon-grade uranium per year.[17] The basis for this estimate was not declassified, although this estimate may have been partially derived from the size of the building, which would have been completed at least a few years before the plant became operational and appears larger than Lanzhou in the recent satellite imagery.

The DIA's estimate corresponds to a plant with a capacity of 120,000-470,000 SWU per year, assuming a tails assay of 0.5 per cent, or 150,000-590,000 SWU per year at a tails assay of 0.3 per cent. At the time, the DIA estimated that the weapon-grade uranium output of this plant would be about 5-7 times larger than the output of the Lanzhou plant at that time. The DIA's upper bound appears too large for the Heping plant, given that it was built during a period when China produced separation equipment that was not optimal.

The capacity of the plant is believed to have improved over the following decade. Citing Western sources, *Nuclear Fuel* reported in 1989 that the capacity of the second plant at that time was a little larger than that of the first plant, or roughly 400,000 to 500,000 SWU per year.[18] However, this information has not been confirmed officially by the Chinese government.

Gas-centrifuge plants

China has conducted R&D on gas centrifuges since 1958. For years, Chinese officials stated that China would build a gas-centrifuge or laser enrichment plant to replace the gaseous-diffusion plants.[19] However, China decided in the early 1990s to buy gas centrifuges from Russia to produce low-enriched uranium for its nuclear power plants and allow the eventual closure of its expensive gaseous diffusion plants.

---

[16] *National Intelligence Estimate, China's Strategic Attack Programs*, NIE 13-8-74, June 13, 1974, declassified version.
[17] *Soviet and Peoples' Republic of China Nuclear Weapons Employment Policy and Strategy*, Defense Intelligence Agency, op. cit.
[18] "China Stops Production of Military Fuel," op. cit.
[19] "China Stops Production of Military Fuel," op. cit.

Inventory of weapon-grade uranium

Lanzhou Plant

China's inventory of weapon-grade uranium can be roughly estimated from the above information. This assessment uses the software Crystal Ball® to calculate distributions of values that estimate the true values. Rather than decide on a best estimate of a specific parameter, such as enrichment plant separative capacity, a frequency distribution of possible values is derived. Distributions representing key parameters in a formula are then sampled using a Monte Carlo approach to derive a distribution of results. This method varies from other approaches where central or best estimates are derived, and an uncertainty is attached by making a judgment about the overall data and information. Although judgments are still necessary in any uncertainty analysis, they can be applied in a more transparent manner with this software.

In this calculation, the key parameter is the separative output of the plant. The production in the Lanzhou plant is estimated to have been about 25,000-50,000 SWU per year from 1964 until the end of 1975. After improvements in the equipment, the capacity is estimated to have increased to about 50,000-150,000 SWU per year during the period from 1976 through 1985. Again following additional renovations of the plant, the capacity reached about 200,000-300,000 SWU per year for the rest of the plant's operation. It is reported that the plant shut down in the late 1990s. During each phase, the separative output is represented by a uniform distribution.

HEU production appears to have ended in the late 1980s; afterwards, the plant made low enriched uranium for power reactors. The exact date when all HEU production stopped is unknown, although press reports have stated that HEU production for weapons stopped in 1987. However, HEU production could have continued for a period of time. In this estimate, all HEU production is assumed to have ended sometime between 1987 and 1989.

Under these assumptions, the median of the estimate of total separative work produced at the Lanzhou plant is 2.27 million SWU during the period of HEU production. The 5^{th} and 95^{th} percentiles are 1.57 and 2.95 million SWU, respectively.

Heping Plant

The output of the second plant is highly uncertain. We assume that it started operating in 1975 at a lower capacity and increased its capacity later. During the period from 1975 through 1985, the plant is assumed to have a capacity of 150,000-250,000 SWU per year, roughly double the capacity of the Lanzhou plant. Afterwards, the capacity is assumed to be 300,000-400,000 SWU per year, until HEU production emded, no later than the end of 1989. The median of the estimate of the total output of this plant is 2.85 million SWU. The 5^{th} and 95^{th} percentiles are 2.26 and 3.46 million SWU, respectively.

The estimate of the total production of the two plants has a median of 5.1 million SWU. The 5th and 95th percentiles are 4.2 and 6.0 million SWU, respectively.

Non-weapon uses

The enrichment programme would have supplied about 685,000 to 915,000 SWU of enriched uranium for several non-weapon purposes, primarily fuel for research, production and naval reactors, and for nuclear weapon tests:

1. China's research reactors would have required 165,000-230,000 SWU by the end of 1987.[20]
2. Production of LEU for five nuclear-powered submarines and one land-based prototype would have required roughly 150,000-200,000 SWU.[21]
3. About 900-1350 kg of weapon-grade uranium would have been consumed in about 45 nuclear weapon tests, where we assume an average of 20-30 kg per test. We assume that China's nuclear weapons depended more on HEU than other weapon states. At a tails assay of 0.3 per cent, this amount of weapon-grade uranium would correspond to 180,000-270,000 SWU.
4. China's graphite-moderated, water-cooled production reactors are believed to have used natural uranium as fuel. The uranium was recovered after reprocessing the irradiated fuel, and it could have been enriched up to weapon-grade uranium. The enrichment level of the feed would have been less than that of natural uranium, about 0.65 per cent for this type of production reactor and a burnup of about 600 MWd/t. Production of weapon-grade uranium (93 per cent ^{235}U) would have therefore required about 5 per cent more SWU per kilogram of product. If China produced roughly 2-3 tonnes of weapon-grade plutonium (see next section), the production of weapon-grade uranium using all the recovered uranium as feed would have required roughly an additional 40,000-65,000 SWU assuming a tails assay of 0.30 per cent.
5. Process losses of 3 per cent would have consumed about 150,000 SWU.

Military inventory

Subtracting these requirements, the estimate of net production has a median of 4.3 million SWU and 5th and 95th percentiles of 3.4 and 5.3 million SWU, respectively. This corresponds to a median of 21.5 tonnes of weapon-grade uranium, assuming an average tails assay of 0.3 percent. The 5th and 95th percentiles are 17 and 26 tonnes of weapon-grade uranium, respectively.

---

[20] IAEA, *Nuclear Research Reactors in the World* (IAEA: Vienna, 1991). Combined, the research reactors could have produced about 270,000-380,000 MWth-d of heat, assuming a 50-70% capacity figure. Two-thirds of this heat was produced by the 125 MWth reactor at the Reactor Operation Institute that uses weapon-grade uranium fuel. Assuming that about 40% of the ^{235}U is fissioned or converted into ^{236}U, fuel for these reactors would require about 165,000-230,000 SWU.

[21] According to *China Today*, Part II, Chinese submarine reactors use low-enriched uranium fuel. A typical naval core is assumed to contain about 1400 kg of 5% enriched uranium fuel (70 kg of 235U). Assuming that a total of 15-20 cores have been fabricated by the end of 1987, total requirements would be 21,000-28,000 kg of 5% enriched uranium, or 150,000-200,000 SWU.

Since the end of HEU production in China in the late 1980s, less than 500 kilograms of weapon-grade uranium are estimated to have been assigned to China's civil research reactors, resulting in a total civil HEU stock of roughly one tonne. Subtracting the amount of HEU assigned to civil reactors after the end of HEU production from the value of 21.5 tonnes gives a median value for the military HEU stock of about 21 tonnes. The 5^{th} and 95^{th} percentiles are assumed to remain the same as above.

Plutonium Stocks

As in the case of HEU production, knowledge of military plutonium stocks remains hazy. China started to produce weapon-grade plutonium in the late 1960s. Over the next decade, it managed to create two plutonium production complexes, although the reactors and reprocessing plants at the complexes reportedly had operational problems. Little public information exists about the third line complex near Guangyuan, although Chinese officials have privately confirmed the complex's existence, at least indirectly, without providing much specific information about the reactor or reprocessing plant.

It is believed that Chinese production of plutonium for nuclear weapons ceased by 1991. However, when or if both reactors have closed is unknown. The lack of information complicates the development of estimates of the total amount of military plutonium produced by China in its production reactors.

Jiuquan Site

China originally intended to import reactors and associated reprocessing facilities from Russia. But by the time Russia withdrew its technical assistance in 1960, China had received only some design drawings and a few items of equipment for a production reactor.[22] None of the key components or equipment had been received. In addition, the reprocessing technology provided by Russia was out-of-date and difficult for China to use.

Because the Lanzhou enrichment plant was further along than the first reactor and reprocessing project, China decided to concentrate on finishing the enrichment plant first. Work on the reactor and reprocessing plants stopped for a time but were resumed in 1962. After the 1964 nuclear test, work on these plants accelerated.

The first production reactor, which started operating in 1966, was a water-cooled, graphite-moderated reactor, located at the Jiuquan Atomic Energy Complex in Subei county (initially code-named Plant 404), approximately 65 miles northwest of the city of Jiuquan in north-central China. The area is mainly desert and very remote.

The reactor experienced frequent technical difficulties and interruptions from the political turmoil caused by the Cultural Revolution. In the early 1970s, the reactor was shut down

[22] *China Today: Nuclear Industry*, op. cit. This reference discusses the Jiuquan reactor in detail, although it omits information on the reactor's power or operating history.

for repair and renovation.[23] In the early 1980s, China decided to convert the reactor into a dual-purpose reactor for producing plutonium and generating electricity. It is unknown if this conversion took place. Some reports state that the reactor stopped plutonium production in 1984, but they are unclear if the reactor stopped making weapon-grade plutonium or stopped operations. One media report states that the reactor was closed in 1984.[24]

All fuels from this reactor were reprocessed on site. The main plutonium separation plant began operating in April 1970.[25] However, plutonium separation started a few years earlier at a pilot separation plant.

China has not stated publicly the power of the Jiuquan reactor. A DIA estimate from 1972 states that total plutonium production is about 300-400 kilograms of plutonium per year.[26] This production rate would correspond to a power of about 1200-1500 megawatt-thermal if the reactor were operated with a capacity factor of roughly 80 percent. This estimate has been challenged by the authors of this report and David Wright and Lisbeth Gronlund, a pair of independent researchers at the Union of Concerned Scientists (UCS) and the Massachusetts Institute of Technology.[27]

Wright and Gronlund used a variety of information about the Jiuquan reactor, including its cooling towers and associated reprocessing plants, to estimate that the initial power of the reactor was about 250 megawatt-thermal (MWth). They assess that during the 1970s, the reactor's power was increased to about 500 MWth.

Satellite Images of Jiuquan

Figure 3 is an image of the Jiuquan nuclear complex that was supplied courtesy of DigitalGlobe and taken March 1, 2004. The Jiuquan complex consists of four separate sites. One site holds the plutonium production reactor and two others are reported to be reprocessing facilities. The fourth site is reported to house a plutonium processing facility to make plutonium metal for weapons components. A uranium hexafluoride production plant is also reported to be at Jiuquan.

Figure 4 shows the plutonium production reactor at Jiuquan. The site is fenced in and is not located on a body of water. The six cooling towers are clearly visible. There are no plumes visible from any of the cooling towers, supporting the information that the reactor is not operating. In addition to the reactor building, there is also a large stack at this site.

---

[23] *China Today: Nuclear Industry*, op. cit.
[24] Mark Hibbs, "China Said to be Preparing for Decommissioning Defense Plants," *Nuclear Fuel*, May 17, 1999.
[25] *China Today: Nuclear Industry*, op. cit.
[26] *National Intelligence Estimate, China's Strategic Attack Programs*, op. cit.
[27] David Wright, Lisbeth Gronlund, and Y. Liu, "Estimating China's Stockpile of Fissile Material for Weapons," draft, Union of Concerned Scientists Technical Working Paper, Washington, DC, April 1996. This paper was revised and published in 2003, see Wright and Gronlund, "Estimating China's Production of Plutonium for Weapons," *Science and Global Security*, 11:61-80, 2003.

Figures 5 and 6 show the probable locations of the reprocessing plants at Jiuquan. One contains the pilot reprocessing plant, and the other has the main reprocessing facility. The pilot plant was closed in the 1970s. These sites have apparent process buildings, stacks, and piping. Figure 6 appears to have a possible injection well.

Figure 7 shows a facility of unknown purpose. It may have a facility to convert plutonium into metal. It is separately fenced. The site has multiple stacks, pipes, and connections between buildings.

Guangyuan Complex

The other plutonium production complex (codenamed Plant 821) is located in Sichuan Province, approximately 24 km west-northwest of the city Guangyuan. Its development began in the mid-1960s as a “third-line” weapon manufacturing facility, further away than Jiuquan from China’s frontiers.

Lewis and Xue state that China’s largest production reactor was constructed at the Guangyuan complex, referring to it as “a very large reactor.” The reactor reportedly started operation in late 1974.[28] Although there are reports of other reactors in China, there is no evidence that there are plutonium production reactors other than the single units at Jiuquan and Guangyuan.[29] The Guangyuan complex also has a reprocessing plant and possibly uranium conversion or fuel fabrication facilities. There also may be facilities unrelated to a strategic nuclear weapons program located at the Guangyuan complex.

Although the initial power of this reactor is believed to be larger than that of the Jiuquan reactor, its power is a matter of speculation. In 1972, the DIA assessed that this reactor had the same power as the Jiuquan reactor and could produce about 300-400 kilograms of plutonium per year, or a power of roughly 1200-1500 MWth.[30] Wright and Gronlund estimated that the power was initially 500 MWth and increased subsequently to 1000 MWth, although the basis of this estimate is less supported than the one for the Jiuquan reactor. An earlier estimate by one of the authors of this report was that the reactor power was roughly 600-750 MWth.[31]

Nuclear Fuel reported in 1999 that the reactor could have still been operating or able to be restarted to make plutonium for nuclear weapons.[32] The sources of this information were western officials and not Chinese officials, however.

---

[28] *National Intelligence Estimate, China’s Strategic Attack Programs*, NIE 13-8-74, June 13, 1974, declassified version.
[29] *China Builds the Bomb*, op. cit., p. 113.
[30] *National Intelligence Estimate, China’s Strategic Attack Programs*, op. cit.
[31] Albright, Frans Berkhout, and William Walker, *World Inventory of Plutonium and Highly Enriched Uranium 1992* (Oxford University Press and SIPRI, Oxford, 1992). These estimates were based on a series of articles, some written by knowledgeable visitors to China, and discussions with European officials familiar with the Chinese military plutonium production program.
[32] “China Said to be Preparing for Decommissioning Defense Plants,” op. cit. See also, Mark Hibbs, “Sino-German Partnership Pursues Managing Chinese Defense Waste,” *Nuclear Fuel*, April 15, 2002.

Satellite Images of Guangyuan

From commercial satellite imagery provided courtesy of Space Imaging and taken on August 15, 2000, the Guangyuan site appears to be composed of six separate clusters of facilities stretching along both sides of a river in a forested, hilly area (see figure 8). The individual sites are relatively isolated and located several kilometers from other developed areas. Not all of the facilities can be positively identified, but some of the functions can be assessed. The groupings of buildings are, by and large, consistent with industrial activities and contain large buildings, many high stacks, and ponds. While some fences are visible, there is no obvious extraordinary security. However, there is only one main road leading to the site.

In general, the Guangyuan complex appears in the imagery to have more activity than the Jiuquan complex. The buildings all appear to be in good repair, and portions of the complex appear to be active.

Figure 9 shows the site of the plutonium production reactor at Guangyuan. This site has a large, high building near its center and a nearby tall stack. The reactor building looks similar in size and shape to the reactor building holding the Jiuquan reactor. This building also appears similar to some of the Soviet plutonium production reactors built in the same era. The operational status of the site cannot be determined from the image.

There are no cooling towers apparent in the image. The reactor is likely cooled by water from the river, possibly with a once-through system, as was the common practice in the early periods of plutonium production in the United States and Russia.

Figure 10 shows a possible plutonium separation or reprocessing facility at Guangyuan. The site contains a long building consistent with other confirmed reprocessing buildings, a large stack, and pipes that could be to pump waste out of the process buildings. The long building is similar to other reprocessing buildings observed by the authors. This facility is the farthest west along the river, but is connected by roads to the other sites. The operational status of the buildings could not be determined from the image. Nuclear waste treatment is likely continuing at this site.

Figure 11 shows two clusters of buildings at Guangyuan. On the left is what appears to be an operational power plant that was likely built to support the operations at the complex. A smoke plume is coming from a tall stack on the side of the building. Next to the stacks could be a cluster of 8 cooling towers. Nearby, the water in the river changes color, which could be caused by an effluent being deposited in the river. In addition to the possible power plant, there are many other industrial looking buildings and stacks at these two areas.

Figure 12 shows a site of undetermined purpose at Guangyuan. It contains one very tall, narrow building, and one set of ponds, but has no stacks. It is the farthest away from the other facilities, and is set away from the river. The site is connected by road to the other Guangyuan facilities.

Figure 13 shows another site of undetermined purpose. This site has many large buildings and stacks. Three of the buildings are very similar, long industrial buildings. Of note in this figure is that the buildings all appear much newer than at any of the other buildings at the Guangyuan complex. The style and appearance of the buildings is also not consistent with the other locations. There also appears to be some sort of access to the river bank from the open space in the middle of the site.

Figure 14 shows an area that could be a support area containing offices and workshops, and serving other needs of the site. It appears part of the Guangyuan complex because of its proximity and the road connecting the areas. Vehicles can be seen parked at a building in the western side of this area.

Inventory of Military Plutonium

China's inventory of military plutonium can be derived from the above information. This estimate draws extensively on the analysis conducted by Wright and Gronlund of the power of the reactors.[33]

Wright and Gronlund estimate that the Jiuquan reactor initially had a power of 250 MWth that was doubled by the early 1980s. They state that this reactor stopped producing plutonium for weapons in 1984, deriving a weapon-grade plutonium production of 0.5 to 1.5 tonnes. The Guangyuan reactor is estimated to have an initial power of 500 MWth that was later increased to 1000 MWth, producing about 1.5 to 3 tonnes of weapon-grade plutonium by the end of production in about 1990.

Total production is therefore estimated as 2-5 tonnes of weapon-grade plutonium. Because of the lack of hard evidence on the production facilities, in particular on the power and operating histories of the reactors, Wright and Gronlund state that their estimates have a high degree of uncertainty.

Wright and Gronlund were unable to determine definitively if the reactors continued to operate after plutonium production for weapons stopped. If the reactors operated longer, they would have likely irradiated the fuel longer to minimize costs, resulting in the production of fuel- or reactor-grade plutonium.

The following estimates the amount of both weapon-grade and non-weapon-grade plutonium produced in these reactors using Crystal Ball® software. The formula to estimate the total amount of plutonium produced in the Chinese production reactors is:

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

[33] "Estimating China's Production of Plutonium for Weapons," op. cit.

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 sensitive parameters in this estimate are the power of the reactors and the average capacity factors.

In this estimate, the operation of each reactor is divided into different phases.

Jiuquan Reactor

For the Jiuquan reactor, the phases are the following:

Phase 1: 1966-1975
During this phase, the reactor experienced a range of technical difficulties and the operators encountered political turmoil from the Cultural Revolution. The power is represented by a triangular distribution with a maximum at 125 MWth and minimum and maximum values at 0 and 250 MWth, respectively. The average capacity factor is represented by a uniform distribution with a minimum of 20 percent and a maximum of 50 percent.

Phase 2: 1976-1979
The power of the reactor increased in this phase and reached 500 MWth by the end of the phase. The power is represented by a triangular distribution with a maximum at 350 MWth and minimum and maximum values at 250 and 500 MWth, respectively. The capacity factor is represented by a uniform distribution with a minimum of 30 percent and a maximum of 60 percent.

Phase 3: 1980-1984
The power is represented by a triangular distribution with a maximum at 500 MWth and minimum and maximum values at 250 and 600 MWth, respectively. The capacity factor is represented by a uniform distribution with a minimum of 50 percent and a maximum of 70 percent.

Phase 4: 1985 onwards
During this phase, the reactor may have continued to operate, but it did not produce weapon-grade plutonium. The power is represented by the same triangular distribution as in phase 3. The capacity factor is represented by a uniform distribution with a minimum of 60 percent and a maximum of 80 percent. A major uncertainty is how long the reactor operated after 1984. Did it shut down following the end of plutonium production for weapons? Did it continue to operate until the late 1990s? This parameter is represented by a uniform distribution with a minimum of 0 years and a maximum of 10 years.

Under these assumptions, the median of total amount of weapon-grade plutonium produced is 750 kilograms with 5th and 95th percentiles of 570 and 940 kilograms, respectively. The median of the amount of non-weapon-grade plutonium is 420 kilograms with a range of 0 to 900 kilograms.

Guangyuan Reactor

For the Guangyuan reactor, the phases are:

Phase 1: 1975-1980
During this phase, the reactor increased its power to 500 MWth, reaching this level at the end of the phase. Reflecting greater uncertainty about the reactor's power, a uniform distribution represents the power of the reactor with a minimum of 100 MWth and a maximum of 500 MWth. The capacity factor is represented by a uniform distribution with a minimum of 40 percent and a maximum of 60 percent.

Phase 2: 1981-1985
During this phase, the reactor power was increased. The power is represented by a triangular distribution with a maximum of 750 MWth and a minimum of 500 MWth and a maximum of 1000 MWth. The capacity factor is the same as in phase 1.

Phase 3: 1986-1991
This phase represents consistent operation of the reactor at nominal power. The reactor power is represented by a triangular distribution with a maximum of 1000 MWth and a minimum of 500 MWth and a maximum of 1100 MWth. The capacity factor is represented by uniform distribution with a minimum of 60 percent and a maximum of 80 percent.

Phase 4: 1992 onwards

During this phase, the reactor is no longer producing weapon-grade plutonium. The distributions for the power and capacity factor are the same as in phase 3. A major uncertainty is how long the reactor operated after 1991. Was it closed in 1991? Did it operate at the end of 2003? This parameter is represented by a uniform distribution with a minimum of 0 years and a maximum of 12 years.

Under these assumptions, the median of total amount of weapon-grade plutonium produced in the Guangyuan reactor is 2000 kilograms with 5^{th} and 95^{th} percentiles of 1560 and 2400 kilograms, respectively. The median of the amount of non-weapon-grade plutonium is 950 kilograms with a range of 0 to 2000 kilograms.

Total Plutonium Production

The median of total amount of weapon-grade plutonium produced in the two reactors is 2800 kilograms with 5^{th} and 95^{th} percentiles of 2300 and 3200 kilograms, respectively. The median of the amount of non-weapon-grade plutonium is 1400 kilograms with a range of 0 to 2600 kilograms.

Given the uncertainties in the dates when the reactors were shutdown, an estimate of total plutonium production is hard to interpret. Nonetheless, such an estimate represents an upper bound on Chinese military plutonium production. The median of total production is 4100 kilograms with a range of 2100 to 6600 kilograms.

The bulk of China's military plutonium is estimated to have been produced in the Guangyuan reactor. As such, this estimate of plutonium production remains highly uncertain.

Figure 1 -- The Lanzhou gaseous-diffusion facility in China.

Figure 2 -- The Heping gaseous-diffusion facility in China.

Figure 3 -- Overview of the Jiuquan Nuclear Complex in China

Figure 4 -- The plutonium production reactor site at Jiuquan.

Figure 5 -- Possible reprocessing facility at Jiuquan.

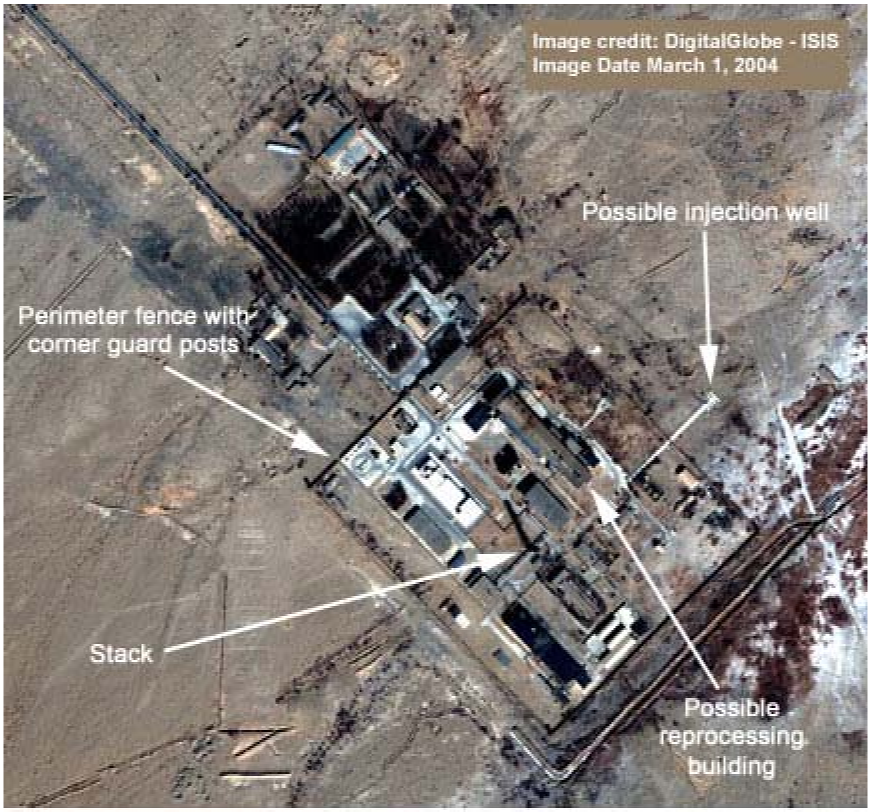

Figure 6 -- Possible reprocessing facility at Jiuquan.

Figure 7 -- Facility of unknown purpose at Jiuquan nuclear complex, possibly a plutonium processing faciltiy.

Figure 8 -- Overview of facilities at the nuclear site at Guangyuan.

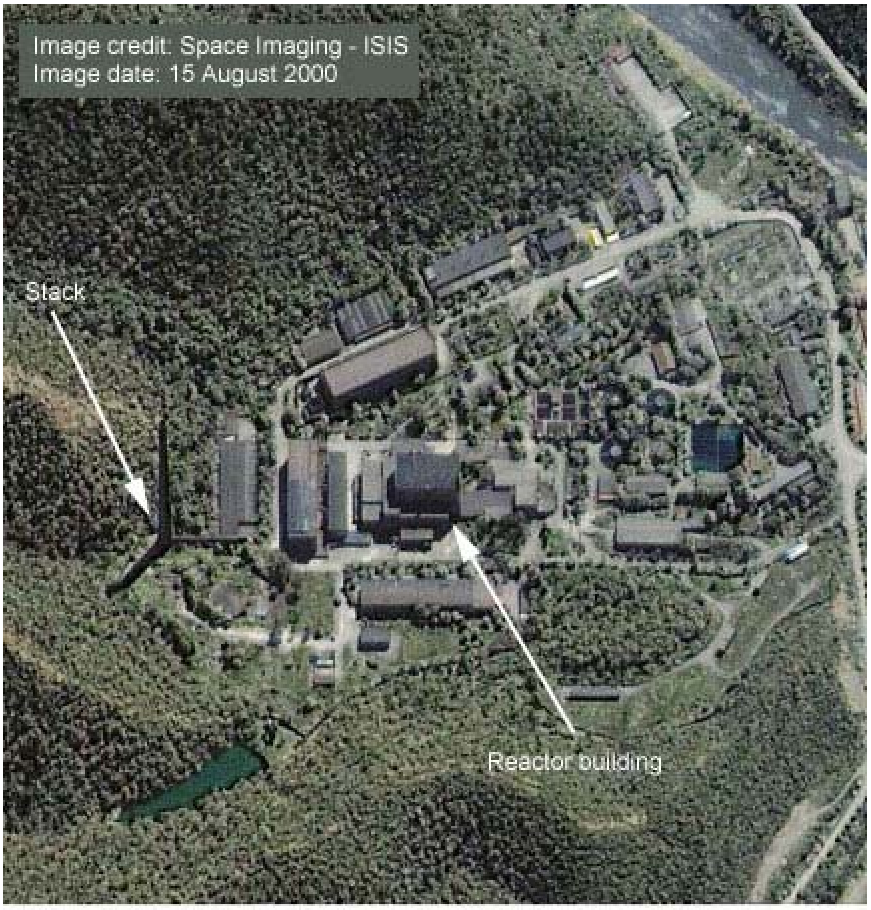

Figure 9 -- Plutonium production reactor site at Guangyuan, China.

Figure 10 -- Possible reprocessing plant and nuclear waste treatment facilities.

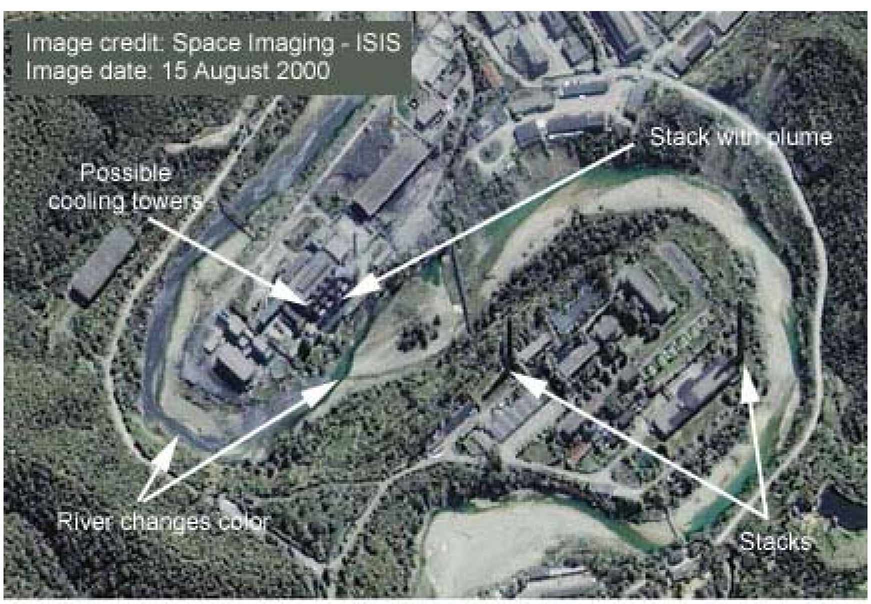

Figure 11 -- Likely operating conventional power plant and other buildings

Figure 12 -- Site of undetermined purpose at Guangyuan, China

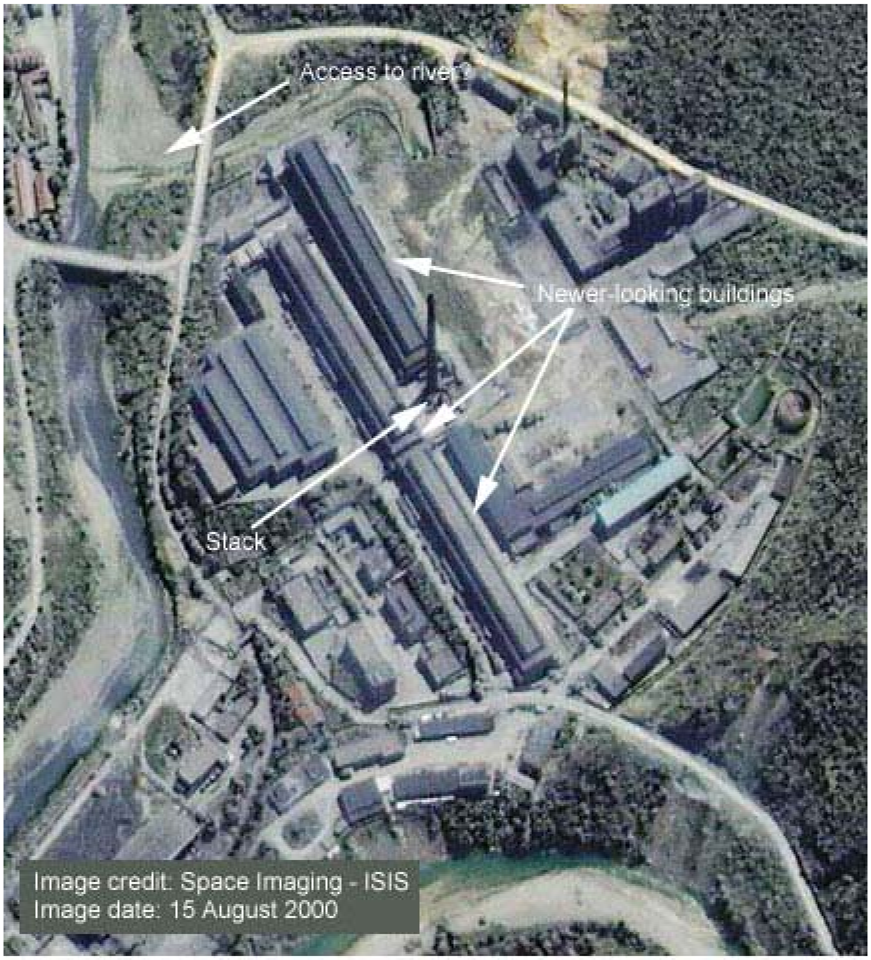

Figure 13 -- Site of undetermined purpose, containing newer-looking buildings

Figure 14 -- Likely support area at Guangyuan, China.