7 China

China launched its nuclear-weapon program in the mid-1950s and began to construct fissile-material production facilities with assistance from the Soviet Union in the late 1950s. Highly enriched uranium (HEU) production began in 1964 and plutonium production in 1966. In the late 1960s, China began to construct a second set of plutonium and HEU production facilities in Southwest China, far from the coast and from the border with the Soviet Union, which came into operation in the 1970s. This "Third Line" program was intended to provide China with backup facilities in case the first production facilities were destroyed.

China has kept information about its stocks of fissile materials and nuclear weapons secret. While China has not declared officially that it has ended HEU and plutonium production for weapons, it is believed to have done so after Beijing began to give priority to its economic and political reforms in 1978. China moved to reduce military HEU and plutonium production, switching some facilities to civilian purposes and closing others, finally stopping production of HEU in 1987 and of plutonium by about 1990.

Table 7.1 summarizes the start-up and shut-down dates for China's military uranium enrichment and plutonium production facilities.

Facility	Start up	Status
Enrichment plants		
Lanzhou gaseous diffusion plant	1964	Stopped HEU production in 1979
Heping gaseous diffusion plant	1975	Stopped HEU production in 1987
Plutonium production reactors		
Jiuquan reactor	1966	Shutdown in 1984
Guangyuan reactor	1973	Shutdown in 1989 (?)
Reprocessing facilities		
Jiuquan intermediate pilot plant	1968	Shutdown in early 1970s
Jiuquan reprocessing plant	1970	Shutdown around 1984
Guangyuan reprocessing plant	1976	Shutdown around 1990

Table 7.1. Operating history of China's military fissile-material-production facilities.

Without knowledge of the operating history and power of China's plutonium-production reactors and the capacities of its uranium enrichment plants, any estimates of China's fissile material stocks will necessarily have great uncertainties.

Based on new public information, the revised estimates reported in this chapter are that China produced 20 ± 4 tons of HEU, 2 ± 0.5 tons of plutonium and currently has stockpiles of about 16 ± 4 tons of HEU and 1.8 ± 0.5 tons of plutonium available for weapons.[473] The values for China's fissile material production are at the low end of most previous independent estimates, which range from 17–26 tons for HEU and 2.1–6.6 tons for plutonium.[474] The new plutonium estimate is consistent, however, with a U.S. Department of Energy assessment from 1999 that China had a stockpile of 1.7–2.8 tons of plutonium for weapons.[475] Arguments supporting a lower estimate for China's fissile material stockpile and its implications can be found in the chapter on China in the 2008 IPFM volume of country perspectives on a Fissile Material (Cutoff) Treaty.[476]

Highly Enriched Uranium

China has produced highly enriched uranium (HEU) for weapons in two complexes:

- The Lanzhou gaseous diffusion plant (Plant 504), and
- The Heping gaseous diffusion plant (Plant 814), a "Third Line" facility

China used these enrichment plants also to produce HEU for its research reactors and LEU for naval reactors. Today, China operates two centrifuge enrichment plants at Hanzhong (Shaanxi province), and at Lanzhou (Gansu province) to produce LEU for civilian purposes. There are also reports of a new plant using Chinese centrifuges near Lanzhou that began operating in 2010.[477]

Lanzhou Gaseous Diffusion Plant. In 1958, with help from the Soviet Union, China started the construction of a gaseous diffusion plant on a bank of the Yellow River in Lanzhou, in Gansu province (Figure 7.1). Two years later, the Soviet Union withdrew its technical experts.[478] The Lanzhou plant produced its first weapon-grade HEU in January 1964 and, over the next few months, enough for China's first nuclear test in October 1964.

There were early efforts by the United States to assess the enrichment capacity of the Lanzhou plant using aerial and satellite imagery, but it proved to be difficult to make reliable estimates. The United States used the U-2 spy plane to photograph the Lanzhou site in September 1959.[479] Progress was revealed by further U-2 photos taken in March and June 1963. U.S. intelligence believed, however, that the processing building was large enough to contain only about 1800 compressor stages, substantially less than the 4000 stages required to produce weapon-grade materials.[480] Moreover, the U.S. government worked on the presumption that plutonium, not uranium, would be the fissile material in China's first bomb.[481] It was therefore a surprise when analysis of residues in the atmosphere from China's first nuclear explosion identified it as an HEU-based bomb.[482] In December 1964, a U-2 flight equipped with infrared detection systems confirmed that the Lanzhou plant was indeed operating.[483]

Figure 7.1 The Lanzhou gaseous diffusion plant in May 1966 and in January 2005 (Coordinates: 36.1507 N, 103.5184 E). The new building visible in the more recent imagery could be the Lanzhou centrifuge enrichment plant (Lanzhou 2), which began operation in 2005 and is listed with a capacity of 500 tSWU/yr. *Sources: KH-7 Mission 4028 (left)*[484] *and Google Earth (right).*

In 1972, the U.S. Defense Intelligence Agency estimated that Lanzhou was producing 150–330 kg per year of HEU.[485] This production rate is equivalent to 23,000–51,000 SWU per year at a tails assay of 0.5 per cent, or 29,000–64,000 SWU per year for 0.3 per cent tails.[486]

China's official nuclear history notes that the capacity of the Lanzhou facility was increased after it started operating, including by the use of a new type of separation membrane.[487] Chinese media reports suggest the design capacity of the Lanzhou plant doubled by the end of the 1970s.[488] Western sources indicate Lanzhou had achieved a capacity of 180,000 SWU per year by 1978.[489]

In 1978, China adopted a policy of economic reform. As part of this shift, it appears that, in 1980, Lanzhou stopped production of HEU and shifted to making LEU for civilian power reactors.[490] In 1981, China began to supply LEU for the international market.[491] Previous estimates of China's HEU production generally have assumed the Lanzhou plant stopped HEU production for weapons in 1987.

Enrichment capacity at Lanzhou increased further during the 1980s, and it was reported in 1989 that the plant was operating at a capacity of about 300,000 SWU per year.[492] In 1998, however, it was decided to decommission the Lanzhou facility as part of a project aimed at replacing China's gaseous diffusion technology with centrifuge enrichment.[493] A new centrifuge enrichment facility provided by Russia with a capacity of 0.5 million SWU per year began operation in 2001. By agreement with Russia, this plant produces only LEU for non-weapons purposes.[494]

Based on the above information, it is estimated that operating continuously at full capacity up to 1980, the Lanzhou plant would have produced 1.1 million SWU.[495] This would be sufficient to produce about 6 tons of weapon-grade (90%-enriched) HEU. It is assumed that, thereafter, the Lanzhou plant produced LEU until 1987, when it ended operations.

Heping Gaseous Diffusion Plant. China built its second gaseous diffusion plant as part of its "Third Line" defense program. The Heping facility (Coordinates: 29.2354 N, 103.0618 E, also known as Plant 814) is located in the Heping Yizu area of Jinkouhe, in Sichuan province. It is believed to have started operating around 1975 and stopped HEU production in 1987.[496] In the late 1980s, based on China's "military-to-civilian conversion" policy, this plant was converted to other purposes, including fluorine production.

Given the paucity of public information available about this plant, there is little basis for more than a rough estimate of its HEU production. Based on satellite imagery the Heping plant had a slightly larger processing building than that of the Lanzhou facility. It is assumed the original capacity of the Heping plant was not significantly larger than that of the Lanzhou plant in 1975, i.e., about 90,000 SWU per year.[497] This reflects the fact that, when Beijing decided to build the Third Line fissile-material production facilities, its first production facilities were just coming into operation and there was no reason for Beijing to build significantly larger backup facilities than those that were being backed up.[498] It also is assumed that, like the Lanzhou plant, the Heping plant roughly doubled its capacity by the end of the 1970s. This is consistent with a report that the output of Heping plant before it shut down was 200,000–250,000 SWU per year.[499]

In this scenario, operating continuously at full capacity up to 1987, the Heping plant would have produced 2.7 million SWU, sufficient to produce about 14 tons of HEU.[500]

Together, the Lanzhou and Heping gaseous diffusion plants therefore would have produced roughly 3.8 million SWU, enough to make abut 20 tons of weapon-grade HEU. This estimate assumes that China used only natural uranium feed for its enrichment program. It is possible that some of China's HEU was produced from reprocessed uranium recovered from its plutonium production reactors.[501] Enriching reprocessed uranium, which contains less uranium-235 than natural uranium, would have required more SWUs per kilogram of HEU produced but the effect would not have been large.[502]

Other demands for uranium enrichment. In addition to producing HEU for nuclear-weapons, China's gaseous diffusion plants also would have supplied enriched uranium for research and naval reactors.

Research reactor fuel. China has had two HEU-fueled research reactors: the 125 MWt High Flux Experimental and Test Reactor (HFETR) and the 5 MWt Min Jiang Test Reactor (MJTR).[503] The HFETR reached criticality in 1979 and converted to LEU fuel in 2007. The MJTR arrived at criticality in 1991 and converted to LEU fuel in 2007. Before conversion, the two reactors would have used together about 1 ton of HEU.[504] This would correspond to about 200,000 SWU at a tails assay of 0.3 per cent.

Russia has supplied China with some HEU fuel for research reactors.[505] China, as of 2003 was estimated to have about 1 ton of civil HEU enriched by itself and by Russia.[506] This civilian HEU supply would have been sufficient to supply China's research reactors. China's use of HEU for research reactors in the future may be insignificant.

China's Experimental Fast Reactor (CEFR), which reached criticality in July 2010, has a first loading of almost 240 kg of HEU (enriched to 64.4 percent uranium-235), provided by Russia.[507] The CEFR will use plutonium-uranium fuel in later loadings, as will China's planned future fast reactors.

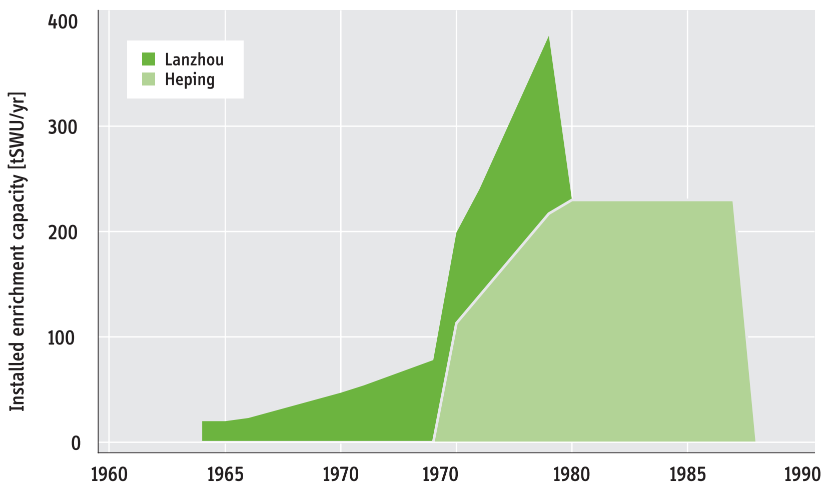

Figure 7.2. Reconstructed history of total enrichment work done by the Lanzhou and Heping GDPs during the periods when they were producing HEU.

Naval reactor fuel. China launched a nuclear-powered submarine program in 1958. Desiring that these submarines not compete with the nuclear-weapon program for HEU, China decided to use less than 5% enriched LEU fuel for its naval reactors.[508] A land-based prototype reactor began tests in May 1970, becoming fully operational in July 1970. The whole-life test of the reactor core ended in December 1979 and the spent fuel was discharged in 1981.[509]

China's first Type 091 Han-class nuclear-powered attack submarine entered service in 1974, and was retired in 2000. It is reported that China currently has four Han-class and two new Type 093 Shang-class nuclear-powered attack submarines in service.[510] The first nuclear-powered strategic ballistic missile submarine (SSBN, Type 092 Xia-class) was launched in 1982 and went on patrol in 1986. One Xia-class SSBN is operational today but it has never gone on patrol.[511]

Each of these submarines has one 90 MWt pressurized-water reactor.[512] If the reactor cores are designed to have lifetimes of 10 years, it is estimated that each fuel load of China's naval reactors would require about 2.3 tons of 5% LEU.[513] The Lanzhou and/or Heping plants would have needed to produce LEU for about 10 naval reactor cores before 1980 to meet the demand for one core for the land-based prototype reactor, five cores for the Han-class submarines, one core for the Xia-class SSBN, and a few spares.[514] This would have reduced the SWU available for making HEU for weapons by about 170,000 SWUs at a tails assay of 0.3 per cent.[515]

Altogether, China's two gaseous diffusion plants would have supplied roughly 360,000 SWU of enriched uranium for non-weapon purposes. This would have left an estimated 3.4 million SWU available for producing weapons HEU, sufficient to produce about 17 tons of weapon-grade material.

Losses and uses of HEU produced for weapons. Some of the HEU produced for weapons was consumed in nuclear weapon tests and process losses.

Nuclear tests. China conducted 45 nuclear-weapon tests.[516] The first seven were carried out before China had plutonium available for weapons and presumably all were HEU weapons, including the 3-megaton thermonuclear weapon test in June 1967. About 200 kg of weapon-grade uranium could have been consumed in these seven tests.[517] In later tests China may have moved to more compact plutonium-based pits for fission weapons and as primaries for two-stage thermonuclear weapons. Assuming that tests with yields significantly above 20 kT were thermonuclear weapons with secondaries containing weapon-grade HEU, then about 550 kg of HEU would have been consumed in these thermonuclear tests.[518] Altogether, nuclear weapons testing may have consumed about 750 kg of HEU or the equivalent of 0.15 million SWU.

Process losses. We assume process losses of about 1 percent, somewhat larger than those reported for the U.S. uranium enrichment program. In this case, about 200 kg of weapon-grade uranium would have been lost during production.[519]

Other. China may have used tens of kilograms of HEU to fuel a tritium-production reactor—say 10,000 SWU.

A. Q. Khan has claimed that China provided 50 kg of weapon-grade HEU to Pakistan in 1982 and 5 tons of LEU enriched to 3%, but many Chinese experts doubt this.[520] Table 7.1 summarizes the above estimates.

Activity	Millions of SWUs produced or consumed
Enrichment work produced when China was producing HEU	3.8
Enrichment work used for non-weapon purposes	
Research-reactor fuel	−0.20
Naval-reactor fuel	−0.17
Tritium-production-reactor fuel	−0.01
Process losses	−0.04
Nuclear tests	−0.15
Provided to Pakistan (?)	−0.01
Total remaining available for weapons HEU	**3.2**

Table 7.1. China's estimated production and use of enrichment work.

Military inventory of HEU. It is estimated that China could have a current inventory of about 16 ± 4 tons of HEU for weapons.[521] This is at the low end of previous estimates.[522]

Plutonium

China has produced plutonium for weapons at two sites:

1. Jiuquan Atomic Energy Complex (also referred as Plant 404) near Yumen in Gansu province. This site includes China's first plutonium reactor, the associated reprocessing facilities; and

2. Guangyuan plutonium production complex (Plant 821), located at Guangyuan in Sichuan province. This "Third Line" site included a plutonium reactor and reprocessing facility.

It is believed that production of plutonium for weapons has ended at both sites. China is interested, however, in reprocessing civilian power-reactor fuel and has built a pilot commercial reprocessing plant. As of late 2010, the facility has not started normal operation.

Jiuquan complex. The Jiuquan plutonium production reactor is a graphite-moderated, water-cooled reactor. It was designed in 1958 with Soviet assistance, and construction started in March 1960. China had not, however, received the key components of the reactor when the Soviet Union ended its support in August 1960.[523] Completion of the reactor project was significantly delayed as Beijing decided to concentrate on completing the Lanzhou enrichment plant. Work resumed on the Jiuquan reactor after the enrichment plant went into operation in 1964. The reactor went critical in October 1966 and went into full operation in 1967.[524]

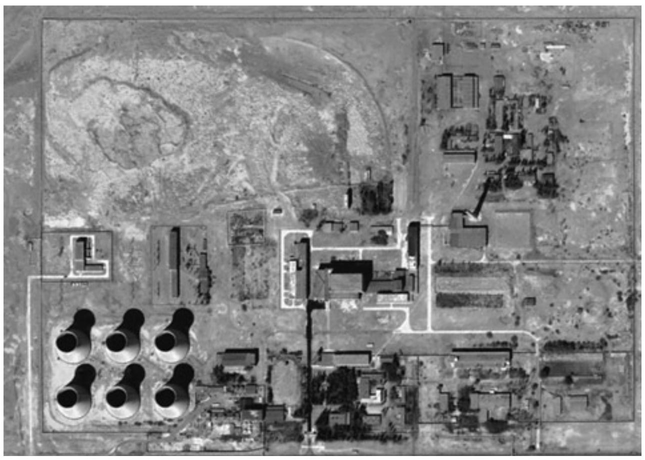

Figure 7.3. The Jiuquan plutonium production reactor, 1 September 2007 (Coordinates: 40.2231 N, 97.3559 E). *Credit: Google Earth.*

During its early years, the reactor encountered a number of technical problems and was frequently shutdown. During the late 1960s and early 1970s, its operation also was affected by the political turmoil of the Cultural Revolution.[525] After 1970, however, the reactor ran without an unscheduled shutdown until it was shut down in 1974 for most of the year for tests, repair and maintenance.[526]

The reactor reached its design power by the first half of 1975.[527] Thereafter, the power and performance of the reactor were increased significantly.[528] As a result of these improvements, by the end of the 1970s, the plutonium production rate had increased 20% (realizing the “1.2 reactor” goal).[529] The reactor was most likely shut down in 1984.[530]

Construction of a pilot reprocessing plant near the reactor site started in 1965 and the plant began operation in September 1968. The plant had two production lines that could together process 0.4 tons of spent fuel per day and operated over 250 days a year.[531] This capacity could separate about 70 kg of weapon-grade plutonium per year.[532] It separated the plutonium for China’s first test of a plutonium-based weapon, which occurred in December 1968.[533] The pilot reprocessing plant stopped plutonium separation when a larger plant, also built near the reactor site, began operating in April 1970.

Power of the reactor. One approach to estimating the Jiuquan reactor’s power is through the size of its six cooling towers. Based on commercial satellite images, it appears that the towers have a top diameter of about 30 meters, which suggests a design power of about 14–140 MWt per tower.[534] Assuming that 85% of the heat was dissipated through the cooling towers and that two towers were kept on standby, the reactor power would be between 70 MWt and 660 MWt.[535] Thus, the cooling tower sizes do not provide the basis of an accurate estimate but do, at least, provide a consistency check for other estimates.

Since Russia helped design the Jiuquan reactor in the late 1950s, the power of Russia's graphite-moderated plutonium production reactors at Mayak at that time may be relevant. Russia's first production reactor, the A reactor, had an initial design thermal power of 100 MWt and, in the period 1950–1954 was operating at about 180 MWt, while subsequent reactors at Mayak were designed with a capacity of 300 MWt (Chapter 3). This suggests China's Jiuquan reactor could have had an initial design power in the range of 200–300 MWt.

Newly declassified information about the unfinished Chinese plutonium-production reactors (Plant 816) at Fuling, in Sichuan province, also provides a way to constrain estimates of the power of the Jiuquan reactor. Beijing decided in 1966 to build three 80 MWt graphite-moderated, water-cooled plutonium-production reactors and associated reprocessing facilities in caves under a mountain near Fuling as a "Third Line" project.[536] If the goal of the project was to build a back-up capacity to the Jiuquan reactor, the planned total power of 240 MWt at the new site probably matched that of the Jiuquan reactor.

Construction started on the Fuling reactors in February 1967. In 1969, given the very slow progress of the work in the mined-out caverns and increasing tensions with the Soviet Union, Beijing decided to meet its urgent need to have a backup for the Jiuquan complex by quickly building a plutonium-production complex at Guangyuan (see below). In 1984, with the Guangyuan reactor operating, and a more benign international security situation, Beijing decided to end Project 816 at Fuling. By then about 85 percent of the civil engineering work had been finished and over 60 percent of the plant equipment had been installed. None of the reactors were ever loaded with fuel, however. The plant was converted to fertilizer production, the project was declassified in 2003, and part of the site was opened as a domestic tourist attraction in 2010 (Figure 7.4).

Figure 7.4. Left: Entrance to the Fuling nuclear complex. The sign in Chinese above the tunnel reads "816 Underground Nuclear Project." Right: Project 816 reactor control room. This image shows core arrangements for three reactors: two to the left and one to the right of the circular display. *Source: www.chinadaily.com.cn/cndy/2010-06/22/content_10000111.htm.*

The history of the Jiuquan reactor and a reasonable set of assumptions about its increase in power from an initial design value of 250 MWt and in its capacity factor indicate how the reactor could have met the goal of the "1.2 reactor." This suggests the Jiuquan reactor could have produced a total of 1050 GWt-days of fission energy and generated a total of about 0.9 tons of weapon-grade plutonium.[537]

Guangyuan complex. As already noted, in 1968, given the slow pace of work on the underground reactor complex at Fuling, Beijing decided to build an alternative "Third Line" plutonium production complex, Plant 821 at Guangyuan, also in Sichuan province. Like the Jiuquan reactor, the Guangyuan reactor was graphite-moderated and water-cooled and presumably of the same design power.

Figure 7.5. The Guangyuan reactor site, 13 February 2006 (Coordinates: 32.4956 N, 105.5901 E). *Source: Google Earth*.

Construction started in 1969, and the reactor achieved criticality in December 1973 and design power by October 1974.[538] By increasing the power and uranium-235 burnup, the plutonium production rate of this reactor was increased 30 percent by 1978, leading to it being dubbed the "1.3 reactor."[539] Thus, combined with Jiuquan's "1.2 reactor," the Jiuquan and Guangyuan reactors were described as "2.5 reactors" by the end of the 1970s.[540] This description reinforces the assumption that the Jiuquan and Guangyuan reactors had similar design power.

It is reasonable to assume that the Guangyuan plant stopped plutonium production by 1989, when, following the new policy of "military-to-civilian conversion," the plant began to convert to civilian use, including aluminum manufacture.[541] The Guangyuan plant was reportedly shut down by 1991.[542] The complex is being decommissioned. The reprocessing plant at the complex started operation in 1976 and reached its design capacity in 1977.[543] It presumably closed in the early 1990s after the last batch of fuel from the reactor had been reprocessed. Given the above information and a reasonable set of assumptions about the increase in operating power and capacity factor of the Guangyuan reactor that helped it achieve the goal of the "1.3 reactor," the Guangyuan reactor could have produced a total of 1,300 GWd and generated a total of about 1.1 tons of weapon-grade plutonium.[544]

Use in nuclear tests. China carried out 38 nuclear tests after it began producing plutonium. Most of these tests could have contained weapon-grade plutonium, either in a simple fission weapon, a compact boosted fission weapon, or as the fission primary in a two-stage thermonuclear weapon. A total of about 200 kilograms of plutonium would have been used in these tests, assuming an average of 5 kg of weapon-grade plutonium per test.[545]

Plutonium inventory. Thus, China's two plutonium production reactors produced an estimated 2 ± 0.5 tons of weapon-grade plutonium.[546] Subtracting the 200 kg of plutonium estimated to have been consumed in China's nuclear tests, its current inventory of weapon-grade plutonium would be 1.8 ± 0.5 tons.

This estimate is at the low end of a U.S. Department of Energy estimated range, reported in 1999, of 1.7–2.8 tons of weapons plutonium.[547] It is also smaller than most previous non-governmental estimates. It is smaller due largely to the assumption that the Jiuquan reactor and Guangyuan reactors had a design power of 250 MWt, whereas earlier estimates assumed that the Guangyuan reactor had a power twice that of the Jiuquan reactor. Earlier estimates also assumed that the power of these reactors increased much more than the 20–30% presumed here.[548] The resulting decrease in estimated plutonium production due to the lower reactor power levels assumed here is somewhat offset by the assumption of higher capacity factors.

China reports no inventory of separated civilian plutonium in its declaration to the IAEA, the most recent of which was for the end of 2007.[549] This situation can be expected to change soon, however. In 2010, China completed and began testing a pilot commercial reprocessing plant with a capacity of 50–100 tons of spent fuel per year. The China National Nuclear Corporation has also proposed to build a commercial-scale reprocessing plant with a capacity of 800 tons per year by 2025.[550] Such a plant could separate about 8 tons of plutonium per year. This would quickly provide China with a civilian inventory of separated plutonium much larger than its military stockpile.

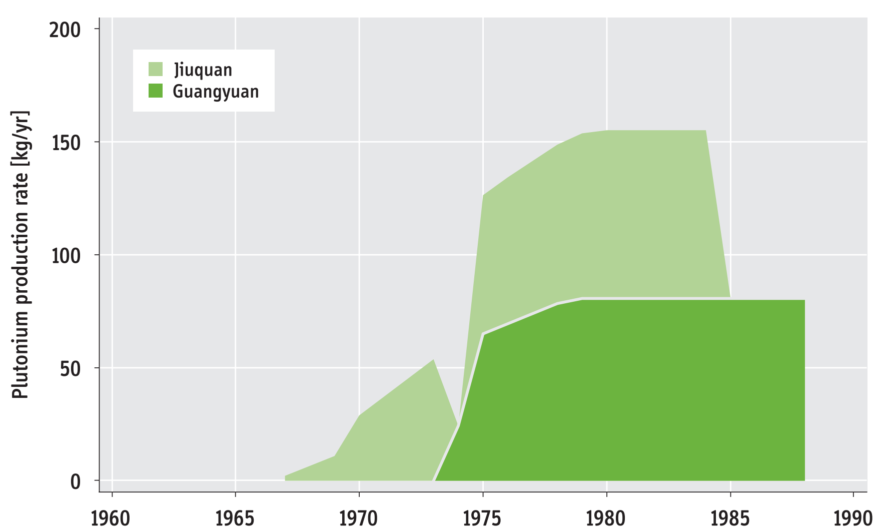

Figure 7.6. Reconstructed history of total production of weapon-grade plutonium by Jiuquan and Guangyuan reactors (tons per year). The two reactors could have produced a total of about 2 tons of weapons plutonium.