THE HISTORY OF PLUTONIUM PRODUCTION IN CHINA

Hui Zhang

Project on Managing the Atom
Kennedy School of Government, Harvard University
79 John F. Kennedy Street, Cambridge, MA 02138

ABSTRACT

China has kept information about its stocks of fissile materials and nuclear weapons secret. Based on new public information, it is believed China halted its plutonium production for weapons in 1987. This paper further reconstructs the history of China's plutonium production at its two plutonium production complexes. Also the paper updates significantly estimates on China's stockpile of plutonium for nuclear weapons. The new estimate is significant higher than other recent estimates.

China has produced plutonium for weapons at two sites: 1) Jiuquan Atomic Energy Complex (Plant 404) in Jiuquan, Gansu province. This site includes China's first plutonium reactor (reactor 801) and associated reprocessing facilities. 2) Guangyuan plutonium production complex (Plant 821), located at Guangyuan in Sichuan province. This "third line" site also included a plutonium reactor (reactor 821) and reprocessing facility. While China has not declared officially that it has ended HEU and plutonium production for weapons, it appears that China halted its HEU and plutonium production for weapons in 1987.[1]

The Jiuquan plutonium production reactor reached criticality in October 1966, and reached its design power in the mid-1975.[2] A great deal of effort went into increasing its plutonium production rate, which was increased by 20 percent by 1979. During the 1980s, after China pursued the "military to civilian conversion" policy, plutonium production decreased rapidly and the reactor was closed by November 1986. The Guangyuan reactor achieved criticality in December 1973 and its design power by October 1974. Subsequently, the plutonium production rate was increased 30 percent by 1978. However, under the "military to civilian conversion" policy, the reactor was shut down in 1984.

Based on then-available information, this author estimated in 2010 that China could have a stockpile of about 1.8±0.7 tons of plutonium for weapons.[3] Based on newly available public information, this study estimates China's current stockpile as about 2.9±0.6 tons of plutonium for weapons. The new estimate for plutonium stockpile is at the high end of a U.S. Department of Energy estimated range, reported in 1999, of 1.7–2.8 tons of weapon plutonium[4] and significantly higher than other recent estimates.[5]

Jiuquan Plutonium Production Complex

In January 1958, the Jiuquan, in the Gobi desert, was selected as the site for China's first plutonium production complex. The Jiuquan plutonium production reactor (reactor 801) is a natural-uranium-fueled, graphite-moderated, water-cooled reactor.[6] Construction began in March 1960. Just after the concrete baseplate was poured, however, in August 1960, the Soviet Union withdrew its experts. At the time, China had not received the key reactor components. Given that the construction of the Lanzhou enrichment plant was much further advanced than the Jiuquan reactor, the Second Ministry decided to suspend the construction of reactor, and make the construction of Lanzhou GDP its top priority. In June 1962, the Second Ministry approved resumption of construction of the Jiuquan reactor. In February 1965, the central government approved speedup of the project to meet the needs of the hydrogen bomb development program. The reactor went critical in October 1966. In December 1967, the reactor achieved 0.5 percent of design power[7]. Since then it had gradually enhanced its operation power until reaching its design power in mid-1975.

During the early years, accidents occurred frequently, due to short of reactor operation experience, lax management, and rule violations. Consequently, it caused the reactor's power to fall below the design level.[8] For a period, damaged fuel elements and aluminum channel liners were frequent, often requiring shut down of the reactor to discharge irradiated fuels and change channel liners and the graphite tubes outside them. After improvements, the reactor achieved continuous operation after 1970, not stopping for fuel loads and discharges or for changing channel liners and or graphite tubes.[9] The reactor ran without an unscheduled shutdown until it shut down in early 1974 for tests, repair and maintenance.[10]

In October 1972, a water tank that bears the weight of the entire reactor core was discovered to be leaking, a year later, in September 1973, the central government approved shut down of the reactor for repair and maintenance. The reactor shutdown on 30 December 1973 for equipment repair and inspection. It took 103 days to resolve the leaking problem.[11] After this work, reactor operation entered a long stable period, with the reactor reaching its design power for the first time in mid-1975. [12]

During and after the last half of 1975, the plant conducted a great deal of scientific research experiments and technical innovation to increase its plutonium production rate. In 1976, the Second Ministry of Machine Building Industry required the enhancement of production output of the reactor as the goal of the Fifth 5-Year Plan (1976-1980). To achieve the goal, the plant undertook a number of major improvements, mainly including 1) increasing the reactor power through improvements in the cooling system; 2) increasing the burnup of the irradiated fuel without losing product quality; 3) increasing the capacity factor, i.e. the reactor operation days per year increased from the original 288 to 324 days per year.[13] As a result of these measures, by 1979, plutonium production had increased by 20 percent, realizing the "1.2 reactor" goal set up for the Fifth 5-Year Plan a year ahead of schedule.[14]

Since 1981, following the "military to civilian conversion" policy, the central government required a relatively large reduction of military nuclear materials production.[15] Thus, entering the 1980s, plant 404 decreased rapidly its plutonium production.[16] The new available information shows that the Jiuquan reactor was closed down by November 1986. [17] In August 1987, at a State Council meeting chaired by then-vice premier Li Peng, it was decided officially to "close the reactor and stop reprocessing (Ting dui ting hua)" and "maintain the plant as a base for civilian reprocessing."[18] After exploring various options during the late 1980s and 1990s, in the 2000s, a pilot civilian reprocessing plant was built at the plant 404 site. [19] Decommissioning of the reactor began after 1990. By 2000, the first the stage, including removal of internal structures of the cooling towers, had been completed.[20]

Figure 1: Jiuquan plutonium complex. Satellite image from 31 December 2012. Credit: Digital Globe and Google Earth, coordinates 40º 13' 50.20"N/97º 21' 49.41"

The military pitot reprocessing plant (referred as Small Plant) at the Jiuquan complex began operation in September 1968. It had two production lines that could together process 0.4 tons of spent fuel per day and operate over 250 days a year.[21] It separated the plutonium for China's first test of a plutonium-based weapon in December 1968. It ended operations when the larger plant, also built near the reactor site, began operating in April 1970. It likely stopped around 1987.[22]

Power of the reactor. In the past, the original design power of the Jiuquan reactor was assumed about 250 MWt. [23]However, based on a recent available authorities publication, it states each Chinese plutonium production reactor had a design thermal power of 600 MWt and 100 MWe.[24] However, it should be noted that while the Jiuquan and Guangyuan reactors were designed for dual-use from the beginning, they did not build to produce power from the beginning.

The new information that each Chinese plutonium production reactor had a same design power is consistent to the facts that the Jiuquan and Guangyuan reactors were described as "2.5 reactors" by the end of 1970s after Jiuquan reactor and Guangyuan reactor realized "1.2" and "1.3" reactor, respectively(which indicated both had a same design power).

The design of Jiuquan reactor should be similar to that of EI-2 reactor at the Siberian Chemical Combine in Seversk (formerly Tomsk-7) near Tomsk, the first dual-purpose reactor constructed in the Soviet Union and started operation in September 1958—several months after Soviet experts began the preliminary design of the production reactor in April 1958. The EI-2 reactor had a design power of 400 MWt (with 100 MWe for electricity generation) and later upgraded to 1200 MWt. it had a closed cooling system. [25]

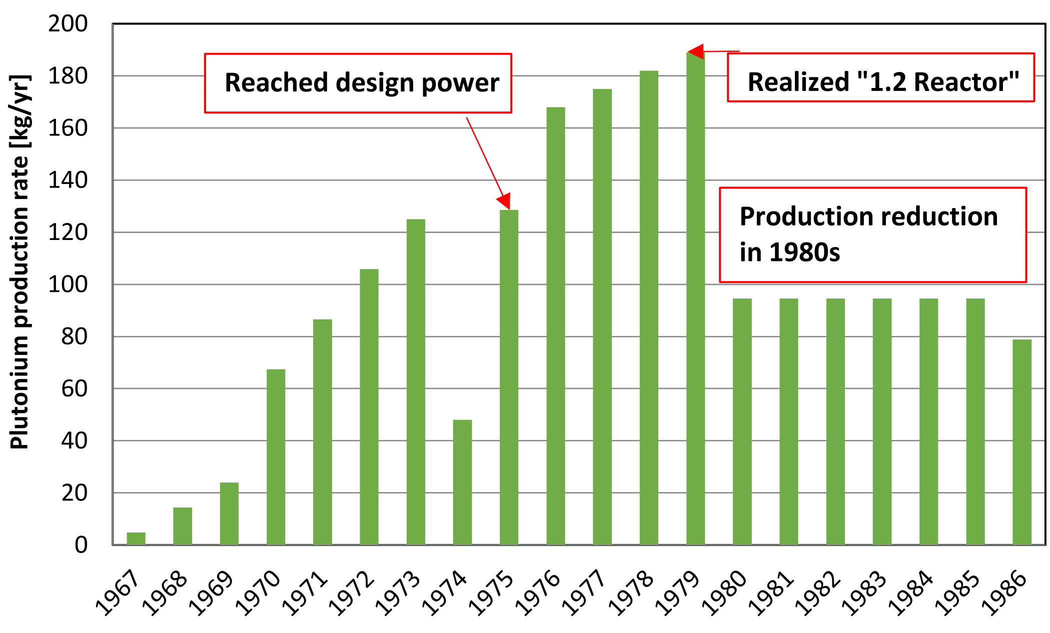
Some may argue that China could never reach its reactor design power of 600 MWt. In fact, many Chinese authorities' publications address that Jiuquan reactor reached its design power by the first half of 1975, and Guangyuan reactor reached its design power in October 1974. Later both reactors increased their powers during the fifth five-year plan (1976-1980) and realized the goal of "2.5 Reactors." In fact, before 1970, a U.S. government official already assumed the Jiuquan reactor design power of 600 MWt.[26]

Plutonium production. The cumulative plutonium production by the Jiuquan reactor is estimated based on the above information and the following assumptions:

- From 1967 through 1973, the reactor power increased linearly from 0.5 percent of design power to about 85 percent of the design power of 600MWt. The capacity factor during 1967-69 is assumed to be 40 percent, and the capacity factor during 1970-73 is assumed to be 80 percent (288 days per year);
- The reactor shutdown for 103 days during January 1974-April 1974 for repair and maintenance;
- From April 1974 through June 1975, the reactor power increased linearly to full design power of 600 MWt with a capacity factor of 80 percent;
- From July 1975 through 1979, the reactor linearly increased its plutonium production rate to 1.2 times the initial design production rate; and
- From 1980 until shutdown in November 1986, the plutonium production rate was about half of that in 1979. [27]

With these assumptions, the Jiuquan reactor produced an estimated total of 2,200 GWd of fission heat and generated a total of about 2 tons of weapon-grade plutonium.[28]

Figure 2: Reconstructed history of production of weapon-grade plutonium by Jiuquan reactor (kilograms per year).



Guangyuan Plutonium Production Complex

After 1964, given the increasingly worsening relationship with Soviet Union and the growing military presence of the United States in the region, China began to construct a second set of plutonium and HEU production facilities in "third line" interior areas in case the first production facilities in border and coastal areas were destroyed. The "third line" facilities were required to be "near mountains, scattered and concealed (later in caves)." In 1966 Beijing decided to build a duplicate to the Jiuquan complex in caves under a mountain as a "Third Line" project (Project 816).[29]Construction started in February 1967. However, the extremely hard rock made the work of mining out the caverns very slow and the project was expected to take a long time to complete. (In fact, under the "military to civilian conversion" policy, the project 816 ended in 1982 while the plant was still incomplete.)

` Given the border conflicts with the Soviet Union had been increasing since the late 1960s and the occupation of Czechoslovakia by Soviet troops in August 1968 suggested that Moscow was willing to use force to resolve ideological differences, Beijing decided to rush the building of an alternative 'third line' plutonium production complex. In October 1968, the Second Ministry started site selection in Guangyuan in Sichuan province. After a fierce border conflict in March 1969 – the Chen-pao Island event – Beijing became seriously concerned about the possibility that Moscow might conduct "surgical strikes" against China's nuclear facilities. In May 1969, Premier Zhou Enlai approved the issuing of a "Joint Notice to Rush Construction of Project 821". [30]

Construction on the reactor started on October 10, 1969. The Guangyuan reactor achieved criticality in December 1973 and design power by October 1974.[31] Like the Jiuquan reactor, the Guangyuan reactor was a natural uranium-fueled, graphite-moderated, water-cooled reactor with a design thermal power of 600 MWt and an electrical generating capacity of 100 MWe.[32]However, it did not build to produce power from the beginning. The Guangyuan reactor used the once-through cooling system which drew cooling water from the nearby Bailongjiang River and discharged heated water downstream.

During the first stage (1973-1976), the Guangyuan plant mainly focused on resolving design and testing issues,[33] including uses of detection devices for monitoring the flow and temperature of water coolant, application of computer system, and improvement of the large water-intake pump to meet the reactor needs of water.

Facing the grim surrounding security situation, in 1976 the Second Ministry of Machine Building Industry required the reactor 801 and 821 to increase its plutonium production and reached the goal of "2.5 reactors" during the Fifth 5-Year Plan (1976-1980).[34] By increasing the power and uranium-235 burnup, the plutonium production rate of the reactor 821 was increased 30 percent by 1978, leading to it being dubbed the "1.3 reactor."[35] Thus, combined with Jiuquan's "1.2 reactor," the Jiuquan and Guangyuan reactors became "2.5 reactors" by the end of 1970s.[36]

Based on new available information, following "military to civilian conversion" policy, the Guangyuan reactor likely started conversion work to the dual mission of plutonium and electric power production in Sept.1984.[37] Some say that conversion was completed in 1986, but because of concerns of safety issues, it never operated. [38] The reactor was likely closed in 1986.[39]

It is reported that, in August 1987, the central government made a strategic decision at the important Beidaihe meeting on the Guangyuan plant of "ending military production and converting to civilian." [40] With parallel actions at Jiuquan complex, it appears that China officially ended its plutonium production for weapons in 1987.[41]

After the shutdown of the reactor, plant 821 began to convert to primarily a civilian mission, including aluminum manufacture. The new enterprise was called the CNNC Sichuan Wuzhou Industry Company.[42] The second volume of the plant 821 history "Plant 821 (1988-2006) discusses the plant's journey to civilian activities. During 1990 -2000, the plant also carried out early-stage of decommissioning of its reprocessing plant. After 2006, plant 821 has renamed the CNNC Sichuan Environmental Protection Engineering Co., LTD, which focuses on decommissioning of nuclear facilities and management of nuclear wastes.[43]

The reprocessing plant at the complex had started operation in 1976 and reached its design capacity in 1977.[44] It presumably closed in 1987.

In addition, some accounts assume China also tried to build another military plutonium production complex (Plant 827) in early 1970s.[45] However, new available information shows that the production reactor associated with the plant 827 was a dedicated military heavy water tritium production reactor.[46]

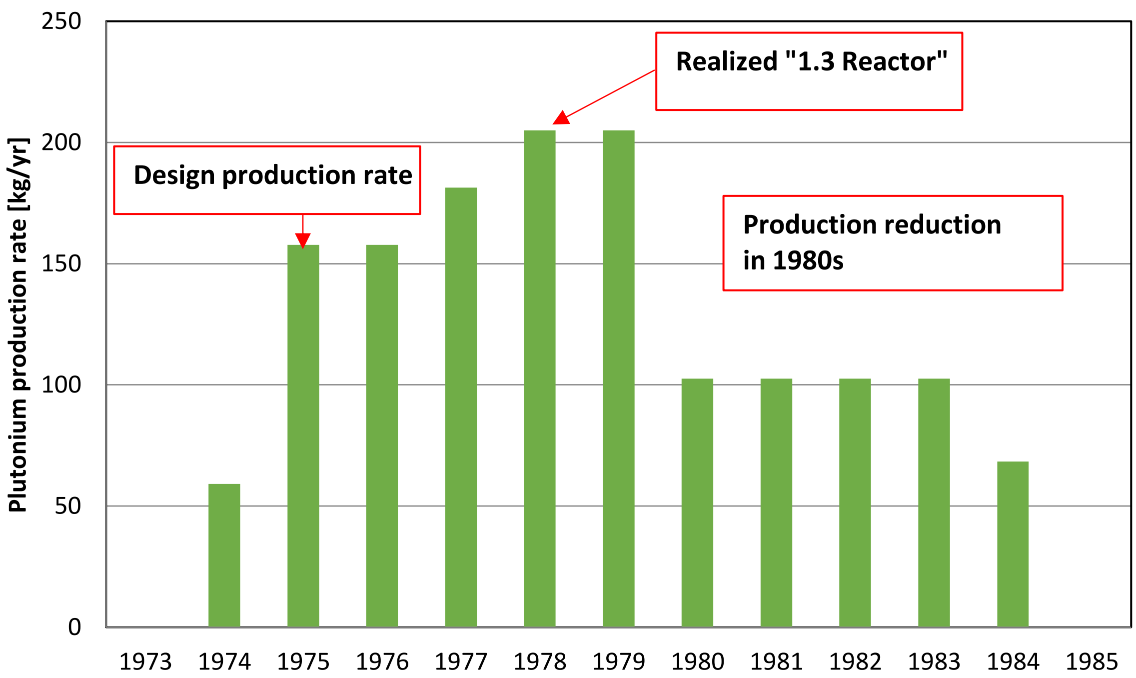
Figure 3: Guangyuan plutonium production complex. This image was taken on 31 October 2015 by a Digital Globe satellite (coordinates: 32^0 29' 44.27" N /105^0 35' 24.48" E) Credit: Digital Globe and Google Earth.

Plutonium production. Estimated cumulative plutonium production by the Guangyuan reactor is based on the following assumptions:

- December 1973–October 1974, the reactor power increased to the design power of 600 MWt with a capacity factor of 40 percent;[47]
- November 1974-December 1976, the reactor power maintained a design power of 600 MWt with a capacity factor of 80 percent;
- January 1977 – December 1978, the plutonium production rate increased linearly by 30 percent; and maintained the same production rate until December 1979;
- From 1980 until shutdown for conversion in August 1984, the plutonium production rate was reduced about half of that in 1979. [48]

Under these assumptions, the Guangyuan reactor could have produced a total of about 1600 GWd of fission energy and generated a total of 1.4 tons of weapon-grade plutonium

Figure 4: Reconstructed history of production of weapon-grade plutonium by Guangyuan reactor (kilograms per year).



Stockpile of Military Plutonium

The Jiuquan and Guangyuan reactors could have produced a total of 3800 GWd, sufficient to produce a total of about 3.4 tons of weapon-grade plutonium. However, after considering China used its plutonium production reactors to produce tritium, and taking into account the amount of plutonium consumed in nuclear tests and lost in reprocessing and fabrication,[49] and allowing for uncertainties of the estimates (about ± 20 percent),[50] China's current inventory of weapon-grade plutonium is estimated at about 2.9 ± 0.6 tons (2.3-3.5 tons). This is significant higher than other recent non-governmental estimates.[51]

NOTES AND REFERENCES

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[1] More details could be read in Hui Zhang, *China's Fissile Material Production and Stockpile*, IPFM Research Report No. 17, Princeton, NJ: Princeton University, 2017 (Forthcoming).
[2] See details in China's official nuclear history: Li Jue, Lei Rongtian, Li Yi and Li Yingxiang, eds., *China Today: Nuclear Industry*, China Social Science Press, Beijing, 1987.
[3] Hui Zhang, "China," in *Global Fissile Material Report 2010: Balancing the Books: Production and Stocks*, Princeton, NJ: Princeton University, 2011.
[4] The U.S. Department of Energy estimate was first reported in Bill Gertz and Rowan Scarborough, "A Nation Inside the Ring", *The Washington Times*, 9 July 1999. A more detailed report on this official estimate was published in Robert S. Norris and William M. Arkin, "World Plutonium Inventories," *Bulletin of the Atomic Scientists*, Sept/Oct.1999, and p. 71.
[5] This is significantly higher than a total of 1.6 to 2.4 tons of plutonium in a recent ISIS estimate. *Military Highly Enriched Uranium and Plutonium Stocks in Acknowledged Nuclear Weapon States*, *op.cit*.
[6] More details about the history of Jiuquan reactor can be read from *China Today: Nuclear Industry, op.cit., Chapter 10, pp.204-215. Also, a blog of Cui* Zhaohui, a former senior engineer of plant 404, "The Life of Sanbei," http://qxzc.net/gr/cuizh/4/4%286%29.htm; Zhou Zhi, "Recollections of the Pioneering Work of Plant 404", 19 August 2007. The author was vice-minister of the former Ministry of Nuclear Industry; http://qkzz.net/Announce/Announce.asp?BoardID=17100&ID=10015168.
[7] *China Today: Nuclear Industry*, pp.210-211.
[8] Zhou, "Recollections of the pioneering work of Plant 404," op.cit.
[9] See, e.g., the blog of Cui Zhaohui, *op.cit.*
[10] *China Today: Nuclear Industry*, p.211.
[11] See, e.g., the blog of Cui Zhaohui, *op.cit.*
[12]*China Today: Nuclear Industry*, p.212.
[13]*China Today: Nuclear Industry*, pp.21-214.
[14] See, e.g., Zhou, "Recollections of the Pioneering Work of Plant 404," *op.cit.*; *China Today: Nuclear Industry*, p.214.
[15] *China Today: Nuclear Industry*, p.80-86.
[16] A blog on The 50th Anniversary Celebration of the Plant 404, Oct.25, 2008. http://blog.sina.com.cn/s/blog_59d3d87c0100ax4j.html.
[17] When one former worker of the plant visited the reactor on November 8, 1986, he addressed in his memoir that the reactor had then closed and ended its historic mission. See his blog: http://blog.sina.com.cn/wjx5511.
[18] See, e.g., a blog on The 50th Anniversary Celebration of the Plant 404, *op.cit*.
[19] Song Xuebin, a former director of plant 404, "Taking Root in Gobi Desert for 50 Years due Sole to the National Needs," *China Nuclear Industry*, no.9, 2008.
[20]Bai Zhiqiang, "Statistic Analysis on the Occupational Radiation Exposure of the First Stage of Reactor 801 Decommissioning," *Proceedings of National Workshop on Decommissioning Plans Nuclear and Radiation Facilities*, 1 November 2007. Mianyang, Sichuan.
[21] *China Today, Nuclear Industry*, p.227.
[22] See, e.g., a blog on The 50th Anniversary Celebration of the Plant 404, *op.cit.*
[23] Hui Zhang, "China's HEU and Plutonium Production and Stocks," Science *& Global Security* 19, no. 1 (January-April 2011): 68-89.
[24] Huang Jianchi and Xi Lisheng, "The Status of China's Production Reactor," *Advances in Earth Science (in Chinese)*, 1990, no.2, p.60-61.

www.adearth.ac.cn/CN/article/downloadArticleFile.do?attachType=PDF&id=10091. Both authors were in the expert panel of strategy study for the State Council' nuclear power office. Huang was the panel director. Also, as a former senior engineer of reactor 801, *Cui* Zhaohui described the design power of reactor 801 as 600 MWe (see, *a blog of Cui* Zhaohui, *op.cit*).

[25] Anatoli Diakov, "The History of Plutonium Production in Russia," *Science & Global Security* 19, no. 1 (January-April 2011): 28-45.

[26] Charles Murphy, "Mainland China's Evolving Nuclear Deterrence," *Bulletin of the Atomic Scientists*, January 1972, p29.

[27] According to the "military to civilian conversion" policy, since 1981 the central government required a relatively large reduction of military nuclear materials production (see, e.g. *China Today: Nuclear Industry*, p.80-86). It is reported that after entering the 1980s, plant 404 decreased rapidly its plutonium production (see, e.g., a blog on the 50th Anniversary Celebration of the Plant 404, *op.cit.*). In practice, the HEU production reduced about half since 1980. Lanzhou and Heping GDPs had a similar production capacity, and Lanzhou GDP was shifted from HEU to LEU production around 1980. Thus, based on the government policy and the HEU production cases, the reactor 801 could reduce production significantly during 1980s before it shutdown. While there is no available information about the detailed reduction rates, the reactor could reduce production at a modest rate in early 1908s, and at a significant cut rate since mid-1980s. Thus, we assume the reactor had an average reduction rate around 50% during 1980-1986. If we assume the reduction rate at 25% or 75%, it could contribute about 10 percent uncertainty to the total plutonium produced in China.

[28] It also assumes the amount of plutonium produced per MWt-day by the Jiuquan reactor is the same as for the EI-2 reactor at Tomsk-7 in Russia that estimated the discharged uranium were with a burnup of 468 MWd/ton and contained 420 grams of plutonium per ton of uranium (see "The History of Plutonium Production in Russia," *op.cit.).* Thus, the reactor is assumed to *produce 0.9* grams of plutonium per MWt-day.

[29] More can be found at CCTV 10 interviews and discussions with experts and former solders involved in the project 816. http://tv.cntv.cn/video/C24886/d393d975879c40a01e674083c59c91f5; and Peng Yining, "Nuclear Reaction to Tourist Attraction," *China Daily*, 22 June 2010, http://www.chinadaily.com.cn/china/2010-06/22/content_10000276.htm.

[30] More details can be read about the history of plant 821 from blogs of Zheng Jingdong, a senior engineer of the plant 821. Zheng read through the first volume of the history of plant 821 "Plant 821 (1969-1987)" edited in 1988. Also he helped to edit the second volume of the history of plant 821 "Plant 821 (1988-2006). Zheng's blogs: http://www.wyzxwk.com/author/c5/463.html. In particular, "Something Can be Spoken—the Original Secrets of Nuclear Industry," June 4,2011 (http://www.wyzxwk.com/Article/lishi/2011/06/230375.html, and the second version at http://bbs.tianya.cn/post-culture-410353-1.shtml); " The Days of Racing to Complete the Plant 821" November 26,2009 (http://www.wyzxwk.com/Article/lishi/2009/11/110302.html); and " Declassified Plant 821 (http://www.aiweibang.com/m/detail/1454501.html?from=p).

[31] Zheng "The Days of Racing to Complete the Plant 821," *op.cit.*

[32] Huang and Xi, "The Status of China's Production Reactor," *op.cit.*

[33] See, Zheng, "Something Can be Spoken—the Original Secrets of Nuclear Industry," op.cit.

[34] See, e.g. "The Intelligent Life of Two Heroes of Nuclear Power," document web of Jiangsu public science and technology: *People* (in Chinese), 14 May 2007, http://hi.baidu.com/lovechild/blog/item/f43d1a7a00a1eaec2e73b359.html. Also *China Today: Nuclear Industry*, p.210.

[35] See, e.g. "The Intelligent Life of Two Heroes of Nuclear Power," *op.cit*.

[36] Zheng, "The Days of Racing to Complete the Plant 821," *op.cit.*

[37] *China Today: Nuclear Industry, op. cit.*, p.91. It addressed the conversion work of plutonium production reactor started in September 1984 and planned to be completed in 1987. But the book did not specify which reactor did. Huang and Xi, in the authority's publication "The Status of China's

Production Reactor" (*op.cit.*) addressed the conversion work of Plant 821 without a mention of reactor 801 conversion. Thus, those publications indicate the Guangyuan reactor could start the conversion work in 1984.

[38] Some accounts mentioned the safety concerns about the dual-use of the plutonium production reactors was incurred by the Chernobyl accident in April 1986, which was also a graphite-moderated reactor.

[39] This is consistent with Zheng's description of reactor 821 that the last stage of the reactor operation was from 1981 to 1986, based on his reading of the history of plant *"Plant 821 (1969-1987)."*

[40]Zuo Xiaojun, a blog of recollections of the author's father, who worked at the plant 821, July 20, 2011, www.zh821.com/Retired-Show.aspx?id=1224. This statement is consistent with a report that plant 404 was required to "close the reactor and stop reprocessing" in August 1987 as well at a State Council meeting (See, e.g. "A blog on The 50th Anniversary Celebration of the Plant 404," *op.cit*.).

[41] The fact that plant 821 released in 1988 its first volume of its history "*Plant 821 (1969-1987)"* may support such a belief.

[42] The company declared bankruptcy in 2009. www.cnnc.com.cn/publish/portal0/tab283/info47848.htm.

[43] Zuo Xiaojun, www.zh821.com/pc/qygk/qyjj.html.

[44] See, e.g., "The Days of Racing to Complete the Plant 821", *op.cit.*

[45] See, e.g. Jeffrey Lewis, "The Untold Story of China's Forgotten Underground Nuclear Reactor," Foreign Policy, July 8, 2014. http://foreignpolicy.com/2014/07/08/the-untold-story-of-chinas-forgotten-underground-nuclear-reactor/.

[46] See, e.g. *Dictionary of World Excellent Experts (online edition)*, no.526, January 2007. In the introduction of Song Yunzhi, a senior engineer, the dictionary emphasized that Song received national awards due to his major contribution to use reactor 801 for mass production of tritium, and saved investment of 0.5-0.8 billion yuan for *military heavy water tritium production reactor* ("JunYong Zhongshui Chanchuan Dui" as described in the dictionary) of project 827.

[47] As the Jiuquan reactor case, we assume the reactor is taken to have produced 0.9 g/MWd for the whole operation period.

[48] As discussed in Jiuquan reactor case, based on the government policy on fissile material reduction in 1980s and the HEU production cases, the reactor 821 could reduce production significantly during 1980s before it shutdown. We assume the reactor had an average reduction rate around 50% during 1980-1984. If we assume the reduction rate at 25% or 75%, it could contribute about 7 percent uncertainty to the total plutonium produced in China.

[49] Zhang, *China's Fissile Material Production and Stockpile, op.cit.*

[50] The uncertainties of the above estimates mainly relate to the assumptions concerning the phase-out of plutonium production during the 1980s. There is no available information on the specific reductions during the period. It has been assumed that the reactors were by 50 percent. If one assumes a range of 25 to 75 percent, the estimate would decrease or increase by 560 kg resulting in a 17 percent uncertainty. Other uncertainties are in the reactor powers, capacity factors, burnups and tritium production during specific periods. This could increase the uncertainty to ± 20 percent.

[51] This is significantly higher than that a total of 1.6 to 2.4 tons of plutonium produced in China by a recent ISIS estimate in *Military Highly Enriched Uranium and Plutonium Stocks in Acknowledged Nuclear Weapon States, op.cit*. One major reason for the lower estimate is that the assumed reactor power is much less than the new available information suggests. Another reason is the capacity factors they assumes is much lower. For instance, they assume the upper bound of the capacity factor until 1980 is about 60%. However, as *China Today* reported one major improvement to increase plutonium production during 1976-1980 was to increase the reactor operation days per year from the original 288 to 324 days per year (i.e. an increase in the capacity factor from about 79% to 89% (*China Today: Nuclear Industry*, p.214).