The History of Highly Enriched Uranium Production in China

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ABSTRACT

China has not declared officially that it has ended fissile materials production for weapons. Based on new public information, this work further reconstructs the history of China's production of highly enriched uranium at its two gaseous diffusion plants, and updates significantly estimates on China's military inventory of highly enriched uranium. The new estimate is significantly lower than most previous independent estimates.

China initiated its nuclear weapon program in 1955 and began to construct its fissile-material production facilities in the late 1950s. China has produced highly enriched uranium (HEU) for weapons at two complexes: Lanzhou gaseous diffusion plant (GDP, also referred as Plant 504) and Heping GDP (the Jinkouhe facility of Plant 814).[1]

In 1958, China started the construction of the Lanzhou plant with advice from Soviet experts. Moscow withdrew all its experts in August 1960, however, forcing China to become self-reliant. On January 14, 1964, the GDP began to produce 90% enriched uranium, which made possible China's first nuclear test on 16 October 1964.[2]

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)." Construction of the Heping GDP started in 1966 and it began operating in 1970.[3]

By the end of 1970s, China increased its HEU production by about 3 times. But in the early 1980s, China adopted a policy of economic reform and decided to reduce HEU and plutonium production.[4] The Lanzhou GDP ended HEU production around 1980 and switched to LEU production for civilian reactors and/or naval reactors. It was closed in December 2000 and replaced by a civilian centrifuge enrichment plant after 2001.[5] The Heping GDP is believed to have stopped HEU production for weapons in 1987. Since then, it is likely operating for non-weapon military uses, or dual use.[6]

Based on newly available public information, this new study estimates China's current stockpile as about 14±3 tons of weapon grade HEU The new estimate for HEU is somewhat lower than the author's estimates in 2010[7] and significantly lower than the recent other estimates.[8]

Currently, China operates three centrifuge enrichment plants at: Hanzhong, Shaanxi province (plant 405), Lanzhou, Gansu province (plant 504), and at Emeishan, Sichuan province, (plant 814) to produce LEU for civilian purposes. As of late 2016, China has commercial SWU

production capacity of around 4.5 million SWU/year.[9] Moreover, besides Heping GDP, Plant 814 is also operating a pilot centrifuge enrichment plant near Emeishan, likely enriching for non-weapons military uses and possibly civilian uses.[10]

Lanzhou Gaseous Diffusion Plant

In August 1956, Beijing and Moscow signed a formal agreement on Soviet assistance to the Chinese nuclear program including the gaseous diffusion plant.[11] In September 1957 the GDP site was finally chosen on a bank of the Yellow River near Lanzhou, Gansu province. In spring 1958, China started the construction of plant. In May 1958, Moscow noticed that it would delivered diffusers of various models by 13 batches between September 1958 and 1959 which required to complete the cascade hall and the auxiliary projects and be ready for installation before the end of 1959. [12] Considering that Moscow refused providing the teaching model of atomic bomb and relevant technical materials for China in June 1959, Beijing was concerned that Moscow would fully break its promise and stop aids. Thus, in late 1959 the Second Ministry leadership requested to speed up the construction of gaseous diffusion plant as soon as possible and learned as much as more from Soviet experts before they left. On December 18, 1959, the construction of main processing building was finished, and on December 27, the first group of diffusers was installed. While the plant entered the important stages of installment, adjustment and operation, Moscow withdrew all its experts in August 1960, however.[13] Thus, China had to rely on its own efforts to move forward with its HEU production program. In November 1962, the plant completed the assembly and installation of all cascades.

In December 1962, the central government approved a "two-year plan" to explode China's first nuclear bomb in 1964.[14] To meet such a deadline, the plant was required to produce HEU ahead of the schedule which was impossible if followed Soviet original startup program of cascades. Finally China used a new program for startup of all of the cascades in nine groups and production of HEU by the fifth group, which was one half year ahead of schedule from the original plan. In April 1963, the plant started up its first group of cascade. Exactly as the calculated program predicted, on January 14, 1964, the GDP began to produce its enriched uranium of 90% uranium-235, which provided the HEU for China's first nuclear test on 16 Oct. 1964. [15] The plant finally completed startup of all cascades thus in full operation in July 1964.[16]

Soon after the GDP produced the first batch of HEU product, as demanded by the Second Ministry in April 1964, for two years from 1964 to 1965 the plant focused on absorbing experience and mastering technical details, increasing operation management and maintenance, and doing R&D and renovation experiments.[17] After these two years, the plant increased gradually its output. There is no available Chinese publications that mentioned about the production capacity of the plant for its early years. In 1971, the Manhattan Project physicist Ralph Lapp, based on the experience of the U.S. Oak Ridge gaseous diffusion plant, estimated that at start-up the Lanzhou plant may have produced about 136 kg per year of weapon-grade HEU and it would have been able to double its annual production by 1966 as operators gained experience with the enrichment process. [18]In 1972, the U.S. Defense Intelligence Agency estimated that Lanzhou was producing 150–330 kg per year of HEU.[19]

China Today addressed that the plant reached its original design capacity by mid-1975. [20] We estimate this capacity to be 100,000 SWU per year (i.e. about 520 kg per year weapon grade HEU at a tails assay of 0.3 per cent).[21]

In August 1975, the diffusion plant proposed a plan to increase its production capacity during the Fifth 5-Year Plan (1976-1980), i.e. a "Program for Increased Output of Primary Products during the Fifth 5-Year Plan." Beginning in 1975, the plant increased the diffuser separation capacity through improvement of separation membranes, raising production capacity by 26 percent. By 1978, cascade flow rates had been increased by 35-47 percent.[22] The GDP increased its production capacity further during the sixth 5-Year Plan (1981-1985), including optimization of cascade arrangements and use of separation membranes with a higher separation efficiency, corrosion and vibration resistance and longer useful lives.[23] The plant reported that the design capacity had been doubled by 1984 ("one plant becomes two plants").[24]

Figure 1: Lanzhou uranium enrichment plant. Satellite image from 18 January 2015 (Coordinates: $36^0$08'53.30" N/$103^0$31'24.49" E). Credit: DigitalGlobe.

After China adopted a policy of economic reform in 1978, it pursued "military to civilian conversion". On October 7, 1979, the Second Ministry submitted to the central government a request to export enriched uranium and received immediate approval from Deng Xaioping.[25] Lanzhou stopped HEU production in 1980 and shifted to producing LEU for civilian power reactors and/or naval reactors. In 1981, China began to supply LEU for the international market.[26]

After 1985, the Lanzhou GDP continued to increase its enrichment capacity including installing higher performance diffusers. Eventually, the capacity increased to 0.25 MSWU/year, 2.5 times its original design capacity.[27] It was permanently closed in December 2000. During 2001 and 2002, the facility was cleansed of uranium and made and ready for decommissioning. Since then, it has been kept in a status described as "sealed and maintenance."[28]

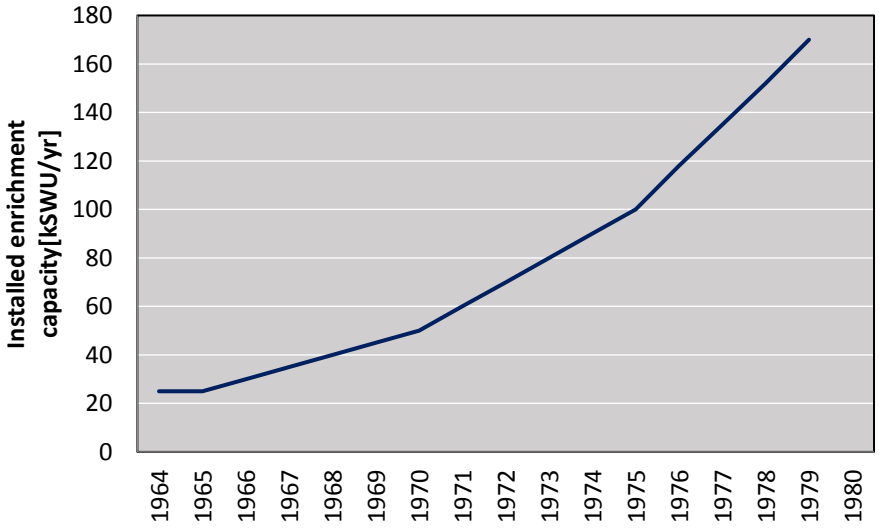
Based on the above information, the following assumptions are made concerning the historical development of HEU production at the Lanzhou GDP:

- From 1964 through 1965, about 25,000 SWU/yr at a tails assay of 0.4 per cent;[29]
- From 1966 through 1970, a linear increase to 50,000 SWU/yr at a tails assay of 0.3per cent;
- From 1971 through 1975, a linear increase to the design output of 100 ,000 SWU/yr at a tails assay of 0.3 per cent; and,
- From 1976 through 1979, a linear increase from 100,000 to 170,000 SWU per year at a tails assay of 0.3 per cent.

HEU production stopped in 1980 at the Lanzhou plant, and it produced LEU from 1980 until December 2000, when it ended operations.

Under these assumptions, operating continuously at full capacity up to 1979, the Lanzhou GDP could have a total capacity of 1.2 million SWU. This would be sufficient to produce about 6.4 tons of weapon-grade HEU (assumed to be 90 per cent uranium-235).

Figure 2: Reconstructed history of enrichment work done by the Lanzhou GDP during the periods when it was producing HEU (thousands of SWU/yr)



Heping Gaseous Diffusion Plant

In March 1964, the Second Ministry began the site selection for a new set of nuclear materials production facilities at the third line area. In November 1965, the site for the second GDP—Heping GDP (the plant 814) was selected at a bank of Dadu river in the Heping Yizu area of Jinkouhe district, Leshan city , in Sichuan province. The site was chosen because it is flat but backed by mountains and had water for cooling. [30]

In 1966, Heping plant started construction. It is reported the plant was constructed by two phases: phase one from 1966 to 1968 and phase two from 1969 to 1972.[31] The first phase of Heping GDP began operating in June 1970.[32] However, in 1972, the U.S. Defense Intelligence Agency estimated that the plant was presently under construction and would probably be fully operational by late 1974.[33] This may be explained as: the plant may have built the two cascade buildings (one for lower enriched uranium and other one for higher enriched Uranium) (see figure 3) as two phases. After phase one was completed, it began operation by batch production approach as did at Lanzhou GDP. And at a low production capacity, it would be difficult for infrared detection system to see.[34]

Figure 3: Heping GDP of Plant 814 at Jinkouhe. Satellite image from September 28, 2013 (Coordinates: 29°13’58.49” N/103°03’49.95” E). Credit: DigitalGlobe

We estimate that the plant reached its original design capacity of 110,000 SWU per year (i.e. about 570 kg per year weapon grade HEU) in 1975. [35] It should be noted that the original capacity of the Heping plant was not significantly larger than that of the Lanzhou plant. However, in its 1972 estimate, the Defense Intelligence Agency estimated that this plant could produce 750-2950 kg of weapon-grade uranium per year. At the same time, the DIA estimated that the Lanzhou GDP produced weapons grade U-235 at a rate of from 150 to 330 Kgs per year.[36] The DIA estimates suggested the enrichment capacity of Heping GDP is much larger than that of Lanzhou GDP, as least two times more.

As Lanzhou GPD did, since 1975, the Heping plant pursued the goal to increase the Output of Primary Products during the Fifth 5-Year Plan (1976-1980). Consequently, the plant increased its production capacity by 1.5 times of its original design capacity by 1980 (i.e. realized a goal of "one plant becomes one and half plant"),[37] which we estimate to be 0.16 million SWU/yr.[38]

Although the central government did not publicly declare a cutoff, the Heping plant ended its HEU production for weapons purpose in 1987.[39] Since 1987, it is believed that it has produced LEU for naval reactors and power reactors and possibly HEU for research reactors. Some Chinese media reported that the plant would close in 2003. But the plant survived through three-year efforts and its production capacity increased by 45% to 0.23 million SWU/yr by 2004.[40]

Since 2007, plant 814 has also operated a small pilot CEP with a capacity of 0.25 million SWU/year near Emeishan city, presumably to produce enriched uranium products for non-weapon military uses or dual use.[41] Around 2013, Plant 814 started to operate a larger commercial CEP plant with a capacity of around 0.8 million SWU/year near Emeishan city.[42]

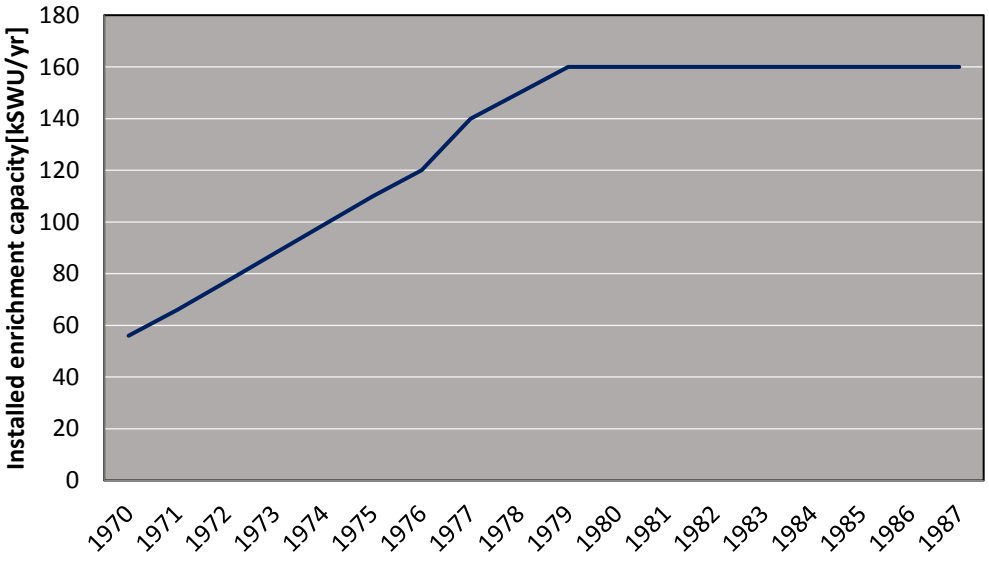
The operating history of the Heping GDP is therefore assumed for the capacity of the plant:

- From June 1970 through 1975, a linear increase from 50,000 to its original design capacity of 110,000 SWU per year at a tails assay of 0.3 per cent;
- From 1975 through 1980, a linear increase from 110,000 to 160,000 SWU per year at a tails assay of 0.3 per cent; and
- From 1981to 1987 the plant operated at 160,000 SWU per year at a tails assay of 0.3 per cent.

In this scenario, operating continuously at full capacity up to 1987 the Heping GDP would have had a total capacity of 2.2million SWU, sufficient to produce about 11.2 tons of weapon grade HEU.

Combined, the Lanzhou and Heping GDPs could have produced about 3.38 million SWU through 1987.

Figure 4: Reconstructed history of enrichment work done by the Heping GDP during the periods when it was producing HEU (thousands of SWU/yr)



Military Inventory of HEU

China's gaseous diffusion plants also would have supplied enriched uranium for research and naval reactors before China ended HEU production for weapons in 1987. It should be noted that China has used LEU for its nuclear-powered submarines.[43] Moreover, some of the HEU produced for weapons was consumed in nuclear weapon tests and went into waste as process losses. Altogether, roughly 700,000 SWU had been used for non-weapon purposes and removals (see table 1).[44]

It is estimated that China could have a current inventory of about 14 tons of HEU for weapons, with an uncertainty of about 20 percent, or about ±3 tons.[45] This new estimate is somewhat lower than the author's 2010 estimates and significant lower than other recent estimates.[46]

Table 1: China's estimated production and use of enrichment work until 1987 when China ended HEU productions for weapons

Activity	Millions of SWUs produced or consumed
Enrichment work produced prior to 1987	**3.38**
Enrichment of irradiated uranium	**-0.2**
Enrichment work used for non-weapon purposes	
Research-reactor fuel	**-0.1**
Naval-reactor fuel	**-0.2**
Other removals	
Process losses	**-0.02**
Nuclear tests	**-0.15**
Provided to Pakistan?	**-0.01**
Total remaining available for weapons HEU	**2.7**

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] Wang Zhaofu, "60 Years of New China's Nuclear Energy Development Key Events," *China Nuclear Energy, 5*, (2009), http://www.china-nea.cn/html/2009-11/4239.html.
[4] *China Today: Nuclear Industry*, p.79.
[5] Jing Yongyu, et al., "Economic Analysis on Decommissioning of Lanzhou Gaseous Diffusion System," *Proceedings of Workshop on Recycling Economics*, 1 July 2008.
[6] See, e.g., Hui Zhang, "China's Uranium Enrichment Complex," *Science & Global Security*, 23:3, 171-190, 2015.
[7] Based on then-available information, this author estimated in 2010 that China could have a stockpile as about 16±4 tons of weapon grade HEU. See, Hui Zhang, "China," *Global Fissile Material Report 2010: Balancing the Books: Production and Stocks*, Princeton, NJ: Princeton University, 2011. http://belfercenter.ksg.harvard.edu/files/Hui-Zhang-China-Chapter-Global-Fissile-Materials-Report.pdf.
[8] This is significantly less than that the roughly 19.4 ±5 tons previously estimated. David Albright and Serena Kelleher-Vergantini, *Military Highly Enriched Uranium and Plutonium Stocks in Acknowledged Nuclear Weapon States*, Institute for Science and International Security, Report, November 2015.
[9] See more details in Hui Zhang, *China's Uranium Enrichment Capacity: Rapid Expansion to Meet Commercial Needs.* Cambridge, Mass.: Report for Project on Managing the Atom, Belfer Center for Science and International Affairs, Harvard Kennedy School, August 20, 2015. http://belfercenter.ksg.harvard.edu/files/chinasuraniumenrichmenntcapacity.pdf.
[10]Hui Zhang, "Assessing China's Uranium Enrichment Capacity," *Institute for Nuclear Materials Management 57th Annual Meeting*, July 24-28, 2016, Atlanta, Georgia, USA
[11] Yingxiang Li, "The Frustrated Course to Start Uranium Enrichment Plant," *China Nuclear Industry*, no.7, 2008, p.56-59.
[12] *China Today: Nuclear Industry*, p.169.
[13] *China Today: Nuclear Industry*, p.172.
[14] *China Today: Nuclear Industry*, p.176
[15] *China Today: Nuclear Industry*, p.168.
[16] CNNC, "Deng Xiaoping and China's Nuclear Industry," *Xinhua Net*, Aug.19, 2003. http://news.xinhuanet.com/newscenter/2003-08/19/content_1034042.htm.
[17] *China Today: Nuclear Industry*, p.178.
[18] Charles Murphy, "Mainland China's Evolving Nuclear Deterrence," *Bulletin of the Atomic Scientists*, January 1972, pp. 28-35.
[19] US Defense Intelligence Agency, *People's Republic of China Nuclear Weapons Employment Policy and Strategy*, Report no. TCS-654775-72, Washington, DC, March 1972.
[20] *China Today: Nuclear Industry*, p.179.
[21] In 2001, a Russian-supplied centrifuge facility (0.5 million SWU/year) was commissioned at the Lanzhou enrichment plant, which was said to have twice the capacity of the GDP (see, e.g. "Establishment of Uranium Enrichment Base Gradually Entering Better Stages and Going

abroad," *China Electric Power News Network*, August 25, 2015, http://www.heneng.net.cn/index.php?mod=news&category_id=9&action=show&article_id=36529). Considering that the GDP had increased to 2.5 times original design capacity (as described later). Thus we can estimate that Lanzhou GDP had an original design capacity of about 100,000 SWU per year.

[22] *China Today: Nuclear Industry,* p.179-184

[23] *Ibid.*

[24] CNNC Lanzhou Uranium Enrichment Co., Ltd, "The Cradle of China's Uranium Enrichment." *The Literature and History of Xigu*, March 4, 2013. http://zx.xglzgs.gov.cn/wszl/2013-03-04/47522.htm.

[25] CNNC, "Deng Xiaoping and China's Nuclear Industry," *op.cit*.

[26] *China Today: Nuclear Industry,* p.180.

[27] Jing Yongyu, et al., "Radiation Protection and Monitoring during Decommissioning of Diffusion System at Lanzhou Enrichment Plant," *Proceedings of National Workshop on the Decommissioning Plans of Nuclear and Radiation Facilities*, November 1, 2007. Mianyang, Sichuan.

[28] Jing, et al., "Economic Analysis on Decommissioning of Lanzhou Gaseous Diffusion System," *op.cit.*

[29] To speed up the production of uranium hexafluoride (UF_6) as the first feed for the Lanzhou GDP, a pilot production facility was built at the Institute of Atomic Energy in the suburb of Beijing. It produced a total of 18.5 tons of UF_6 by October 1963, the first feed for the Lanzhou GDP (see, e.g. Wang, "60 Years of New China's Nuclear Energy Development Key Events," *op.cit*.). The enriched products from this first feed were fabricated into two weapon cores prepared for Chinese first nuclear test (see, e.g., Zhaohui Cui, a former senior engineer of plant 404, "*The Life of Sanbei*," http://qxzc.net/gr/cuizh/4/4%286%29.htm). Assuming the feeding materials of 18.5 tons of UF6 were used to produce 90% enriched uranium, it would produce HEU about 57 kg, 43 kg and 29 kg in a tails assay of 0.3%, 0.4% and 0.5%, respectively. Given the produced HEU was sufficient enough for two bombs as described above, and assuming China used about 20kg for each of its implosion HEU bomb, then it could exclude a tails assay of 0.5%. On the other hand, with a limited initial enrichment capacity, China could achieve a higher HEU production rate by feeding through more natural uranium but separating out the uranium-235 with low efficiency, leaving most of the uranium-235 in the tails (i.e. a tails assay of 0.4%). Thus, it is reasonable to assume a tails assay of 0.4% at the early stage. However, to save more natural uranium, China would move quickly to lower assay (i.e. 0.3%) as its enrichment increased.

[30] CNNC, "Deng Xiaoping and China's Nuclear Industry," *op.cit.*

[31] A blog of "Tracing to the Origin of Jinkouhe District of Leshan City," *op.cit.* http://xzqh.info/bbs/read.php?tid=134140.

[32] Wang, "60 Years of New China's Nuclear Energy Development Key Events," *op.cit.*

[33] US Defense Intelligence Agency, *People's Republic of China Nuclear Weapons Employment Policy and Strategy, op.cit.*

[34] Indeed, until December 1964, a U-2 flight with equipped infrared detection systems confirmed that Lanzhou GDP was operating, after all the cascades started up in July 1964. See, e.g. Lawrence and Woo, "Infrared Imagery in Overhead Reconnaissance," *op.cit*.

[35] As shown below, after a capacity increase of a factor 1.5, the enrichment capacity was 0.16 million SWU/yr.

[36] US Defense Intelligence Agency, *People's Republic of China Nuclear Weapons Employment Policy and Strategy, op.cit*.

[37] In an introduction of contribution to enrichment plants made by Kang Zujie, a former leader of plant 405 and engaged in construction and operation of plant 504 and 814 as well, it addressed that Kang played a key role to achieve the plant's goal of "one plant becomes one and half plant" during the Fifth 5-Year Plan(1976-1980).
http://blog.sina.cn/dpool/blog/s/blog_6ce13f9b01016yaw.html.

[38] Considering a combination of an increase of 45% of Heping GDP production capacity with the capacity of the pilot CEP and the first larger commercial CEP near Emeishan city , it is reported that the plant 814 increased its total production capacity to 8 times of the production capacity of Heping GDP before 2001, see Sichuan National Defense Workers' Union, "The Backbone of National Defense: the story of Du Weihua, a national labor model and director of CNNC Plant 814," *News of China Defense Industry, Postal and Telecommunications Workers' Union*, May 25, 2010. http://gfyd.acftu.org/.

[39] To deepen the military to civilian conversion policy, available information shows that the central government made official decisions on ending plutonium production in 1987 (Zhang, *China's Fissile Material Production and Stockpile, op.cit.*). The Lanzhou GDP started LEU production for civilian around 1980. Thus, an end of HEU production for weapons at Heping GDP in 1987 is reasonable and consistent with Beijing's policy on further reduction and stop of fissile material production in post-1985. Also, it is consistent to numerous discussions between the author and Chinese experts conducted in the past years.

[40] Sichuan National Defense Workers' Union, "The Backbone of National Defense: the story of Du Weihua, a national labor model and director of CNNC Plant 814," *op.cit*.

[41] Zhang, "Assessing China's Uranium Enrichment Capacity,"*op.cit.*

[42] Zhang, "China's Uranium Enrichment Complex," *op.cit.*

[43] Hui Zhang, "Chinese Naval Reactors," IPFM Blog, 10 May 2017.
http://fissilematerials.org/blog/2017/05/chinese_naval_reactors.html.

[44] See details in Zhang, *China's Fissile Material Production and Stockpile, op.cit.*

[45] The 20% uncertainty assumed for the estimated HEU production is due mainly to the range of possible tails and the detailed operation history. For natural uranium feed producing 90% HEU, at a given separative work capacity, a tails assay of 0.4 % would produce about 13% more HEU than for a tails assay of 0.3%. There is no official information about tails assays in China's gaseous diffusion enrichment program. Another major uncertainty is related to the production outputs at specific periods, which could eventually lead to an uncertainty in the cumulative production of SWUs about 5%. Finally, it should be noted that a huge uncertainty of HEU stocks could come from Heping GDP. Here we assume it stopped HEU production for weapons by 1987. Later, if it still produces mainly HEU, it would accumulate a larger HEU stocks. For example, an enrichment capacity of 0.23 million SWU/year would produce about 1.2 tons of 90% HEU each year. Also the pilot CEP with a capacity of 0.25 million SWU/yr could produce about 1.3 tons of 90% HEU each year. Eventually, it would significantly larger than assumed here and would beyond the range given here.

[46] Albright and Kelleher-Vergantini, *Military Highly Enriched Uranium and Plutonium Stocks in Acknowledged Nuclear Weapon States, op.cit*. One major reason for the higher estimate is that the assumed enrichment capacity of Heping GDP is much larger than the new available information suggests.