Assessing China's Plutonium Separation and Recycling Programs

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Abstract

China pursues actively its closed fuel-cycle policy. In 2010, it began testing a pilot civilian reprocessing plant (50 tHM/year). In 2015, China began construction of the demonstration reprocessing plant (200 tHM/year). China has also been negotiating with France over the purchase of a commercial reprocessing plant with a capacity of 800 tHM/year. China's Experimental Fast Reactor (20 MWe) started operation in 2010. Construction of the CFR-600 demonstration fast reactor began in 2017. This work will assess those plutonium separation and recycling programs. Further, it will estimate their cumulative plutonium production and discuss the potential uses of separated plutonium in China's fast reactors over next two decades.

Since 1983, China has officially planned to reprocess spent fuel from nuclear power plants to recover and recycle the plutonium and uranium. Since 2004, when China shifted its nuclear power development policy from "moderate development" to "active development", it has implemented a three-stage plutonium-recycling strategy: pilot, demonstration, and commercial facilities. Although the pilot facilities did not perform well, in 2015 China advanced to the second stage, which includes building a demonstration reprocessing plant, a mixed-oxide fuel facility, and two demonstration liquid-sodium-cooled fast-neutron reactors.[1] Meanwhile, the CNNC has pushed toward the third stage by negotiating with France's nuclear fuel-cycle company Orano (formerly Areva) over the purchase of a large commercial reprocessing plant, and has proposed starting construction of large commercial fast-neutron reactors in 2028.

China's Civilian Reprocessing Programs

In July 1986, the State Council approved the construction of a pilot civilian reprocessing plant with a design capacity of 50 metric tons of heavy metal per year at the Jiuquan nuclear complex, known as Plant 404, as a key project of the national high-technology research and development "863 Program" initiated in March 1986. Construction of the plant started in 1998 and finished in 2005. The construction process encountered numerous difficulties, delays, and higher-than-expected costs. Finally, 24 years after the project's approval, in December 2010, a hot test was conducted. However, due to technical problems, the plant operated for the equivalent of only about 14 days during its first six years, from December 21, 2010 to December 31, 2016, for an average capacity factor of about 0.4% (see table 1). According to one conference report, the pilot plant began operating normally in 2017.[2] If so, it would produce 500 kilograms of plutonium per year. However, others have argued that in the three years from 2017 to 2019 China finally completed the task of reprocessing 50 metric tons of spent fuel accumulated between December 2010 to 2019. Thus, China may have reached a civilian plutonium stockpile of at least 500 kg by 2019, for an average capacity factor of about 5% between December 21, 2010 and December 31, 2019. However, China has not submitted official reports to the IAEA since 2017.

Table 1: China's civilian plutonium separation at the pilot reprocessing facility (2010 to 2019)[3]

Year	2010	2011	2012	2013	2014	2015	2016	2017-2019[c]
Accumulated amount (kg)	13.8	13.8	13.8	13.8	25.4	25.4	40.9	500?
Rate (kg/yr)	13.8	0	0	0	11.6	0	15.5	153
Equivalent operation days[a]	4.6	0	0	0	3.9		5.2	51
Capacity factor	46%[b]	0	0	0	1%	0	1.4%	14%

Note: a) Assuming in one day the facility operates at a full capacity of 300kg of spent fuel, and one ton of spent fuel contains about 10 kg of separated plutonium, then one equivalent full day separates about 3 kg of plutonium. b) Given it started operation on December 21, 2010, the maximum operation time in 2010 would be about ten days. c) Assuming 459.1 kg of separated plutonium was produced between 2017 and 2019 at an average rate of 153 kg of plutonium per year, a total of 500 kg of plutonium would have been produced from 2010 to 2019.

Although the pilot plant did not perform well, in July 2015 the CNNC started construction of the demonstration reprocessing plant in Jinta, Gansu Province.[4] The plant, with a planned capacity of 200 tHM/yr, is to be commissioned in 2025. While there was news coverage of the groundbreaking ceremony at the CNNC Gansu Nuclear Technology Industrial Park that hosts the demonstration reprocessing plant and the demonstration MOX facility, information on the location and construction progress has been scarce. Based on available information and satellite imagery, however, the location of the demonstration reprocessing and mixed-oxide facilities are identified as shown in Figure 1.[5]

Satellite images show that the reprocessing facility has been under intensive construction. Comparing satellite images taken on different dates also demonstrates that the plant is being built at a fast pace. Meanwhile, in late 2019, the company started to order equipment for the reprocessing facility. In December 2019, the CNNC issued a tender for a fluid-bed facility for the reprocessing plant, which should be received by September 2020.[6] Those building activities show the plant could complete its civil engineering stage and enter the equipment-installation stage in 2020. However, the current COVID-19 pandemic may affect its progress.

The CNNC is also building a demonstration mixed-oxide fuel-fabrication line with a capacity of 20 metric tons per year near the demonstration reprocessing plant. The plant is to provide fuel for initial demonstration with fast-neutron reactors. Construction began on the mixed-oxide fabrication plant on June 3, 2018.[7] In 2019, the company started to order equipment for the plant and opened a bidding period between August 29 and September 3, 2019 for a package of chemical analysis equipment. This equipment should have been received before the end of 2019.[8]

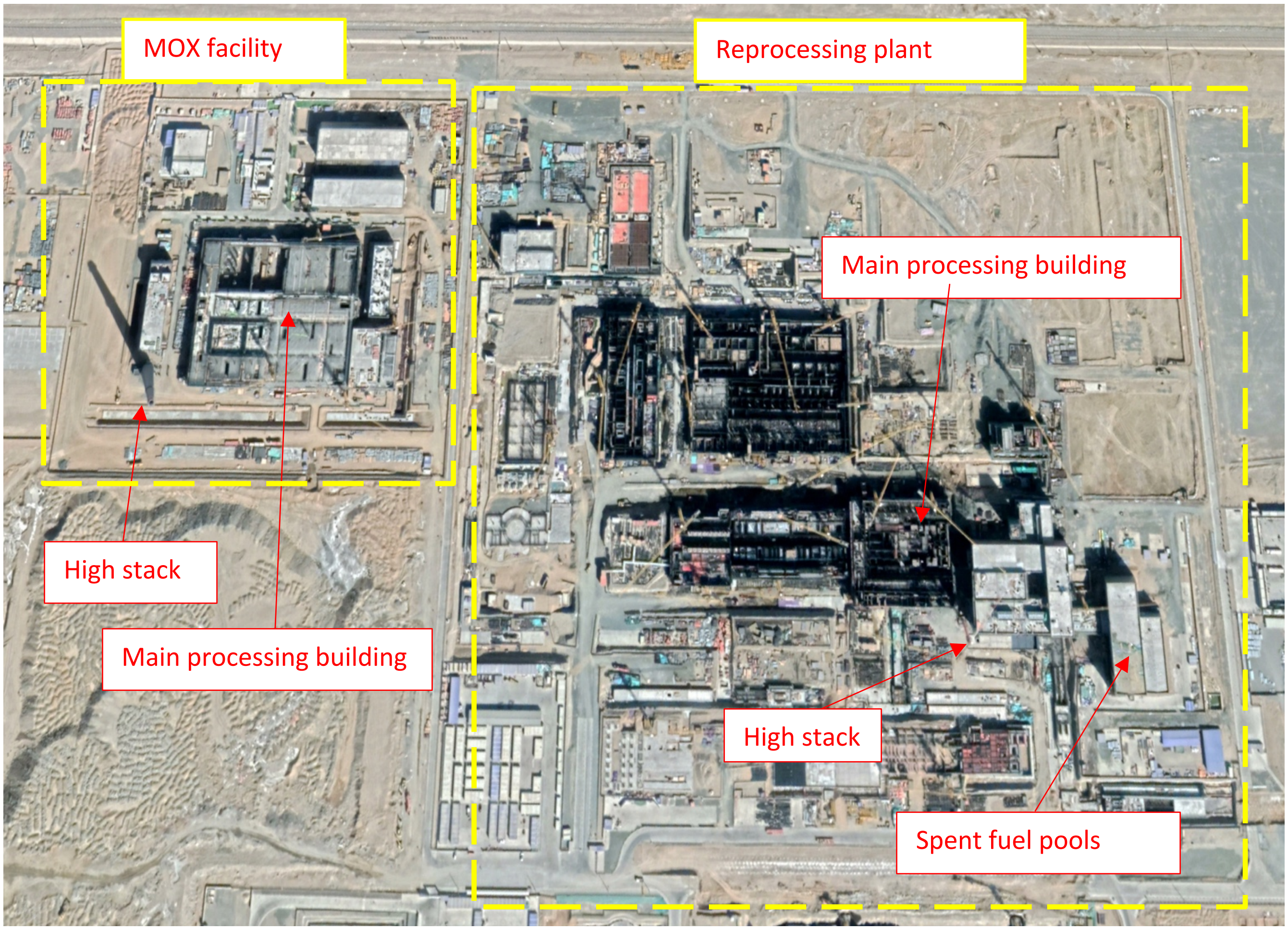

Figure 1: The demonstration reprocessing and MOX facilities under construction at Jinta, Gansu. Satellite image from March 12, 2020 (Coordinates: 40°19'29.74"N 98°30'53.30"E). Credit: Maxar Technologies and Google Earth.

To ensure the successful on-time completion of the project, in March 2019 the CNNC organized its five major construction companies to select personnel with experience in nuclear power project management.[9] The intensifying construction and bidding activities show that the reprocessing and mixed-oxide fuel facilities could complete the civil engineering stage and enter the equipment-installation stage in 2020. They can be expected to be operational by 2025.

Further, since 2007, the CNNC has been negotiating the purchase of a commercial reprocessing plant with a capacity of 800 tHM/year from France's Orano In June 2015, the negotiations took a significant step: the participants completed technical discussions and advanced to negotiating business aspects.[10] However, it seems the CNNC and Orano have yet to reach agreement on the key issue of price.

The 800 tHM/yr plant could be sited in China's eastern coastal region. In July 2015, CNNC Ruineng started working on a preliminary evaluation of seismic safety at two pre-selected coastal sites for the proposed plant, planning for a spent-fuel storage capacity of 6000 tons with two phases and a reprocessing capacity of 800 tHM/yr. The evaluation was to be finished by 30 September 2015.[11] One of the pre-selected sites for the reprocessing plant in Lianyungang, Jiangsu province, however, was cancelled in August 2016 after a protest by thousands of people.[12] It is not clear at the moment when the long-delayed plant will start construction.

China's Fast-Breeder Reactors Programs

Like the pilot reprocessing plant, the China's Experimental Fast Reactor (CEFR) program came about as part of the "863 Program" in 1986. It is a sodium-cooled, experimental fast reactor with a power capacity of 20 MWe (65MWt). In May 2000, China began construction on the CEFR.[13] The reactor went critical in July 2010 and briefly operated with 40 percent of its full power incorporated into the grid in July 2011. It operated at full capacity for 72 hours in December 2014. It has operated intermittently since then, for a cumulative 26 equivalent full-power days between July 2011 and 2018. Its lifetime capacity factor from 2011-2018 was, therefore, only about 1% (as shown in Table 2).

Table 2: China's CEFR operation performance (2011 to 2018)[14]

Year	2011	2012	2013	2014	2015	2016	2017	2018
Equivalent operation days[a]	0.04	0	0	8.12	3.94	13.8	0	0
Capacity factor	0.02%	0	0	2.2%	1.1%	3.8%	0	0

Note: a) The equivalent of one full-power day.

In 2013, the CNNC began focusing on the development of an indigenous 600-megawatt fast reactor (the CFR-600) as a demonstration project. In December 2017, the construction of CFR-600 commenced at Xiapu, Fujian, with plans to begin operating in 2023. On January 18, 2020, the first CFR-600 reactor finished the civil engineering phase and entered the equipment-installation stage, 13 days ahead of schedule.[15]

Newly available information also reveals that the CNNC is actively preparing to construct another CFR-600 at the same site. In November 2019, the corporation announced that the second CFR-600 is to have the same design as the first and to be co-located just to the west (as shown in Figure 2). The second reactor will also share some auxiliary facilities with the first.[16] The first concrete will be poured as early as the end of 2020, and the reactor will be commissioned around 2026. However, the COVID-19 pandemic could have an impact on the construction timeline.

Figure 2: Satellite image over CFR-600 reactor site. Satellite image taken December 11, 2019 (Coordinates: 26°47'59.78"N 120° 9'12.00"E). Credit: Maxar Technologies and Google Earth.

Moreover, CNNC experts have proposed developing the first commercial fast reactor—a 1,000 megawatt CFR-1000 or 1,200 megawatt CFR-1200—based on the experience gained from the CFR-600 project. The corporation plans to complete the pre-concept design and to make a decision to proceed by 2020, and then to finish the conceptual and preliminary designs by 2024 and 2028, respectively. It is to start construction in 2028 and operation in 2034.[17] However, at the moment it is not clear when or if the project will go forward.

Projections of Cumulative Plutonium Separated from PWR Spent Fuels[18]

Based on China's reprocessing programs and the assumptions in Table 3, Figure 3 projects four different scenarios for China's reactor-grade plutonium separation from PWR spent fuel through 2040. The high-production scenario assumes that China separates 0.5 tons of plutonium per year at its pilot reprocessing plant from 2020 to 2040; that the 200 t/year demonstration reprocessing plant is operational in 2025 and separates 2 tons per year; and that the 800 tons per year commercial reprocessing plant comes online in 2035 and separates 8 tons per year thereafter.[19]

Table 3: Scenarios and assumptions for cumulative plutonium separated from PWR spent fuels from 2020 to 2040

Scenarios	Assumptions
Case 1 (Full)	1) The pilot plant operates at full capacity (0.5 t pu/yr) from 2020 to 2040 and had a stock of 0.5 t separated plutonium by 2019. 2) The demo reprocessing plant operates at full capacity (2 t pu/yr) from 2025 to 2040. 3) No 800 tHM/yr reprocessing plant is built.
Case 1 (Half)	The pilot and demonstration plants operate at half capacity of Case 1 (Full).
Case 2 (Full)	1) The same assumptions as in Case 1(Full), except the 800 tHM/yr reprocessing plant is built. 2) One 800 tHM/yr reprocessing plant operates at full capacity (8 t pu/yr) from 2035 to 2040.
Case 2 (Half)	The pilot, demonstration, and 800 tHM/yr plants operate at half capacity of Case 2 (Full).

As shown in Figure 3, under the high scenario of separated plutonium production, Case 2 (Full), approximately 18 tons and 91 tons of separated plutonium would be produced cumulatively through PWR spent-fuel reprocessing by 2030 and 2040, respectively. The low-production scenario, Case 1 (Half) assumes the pilot and demonstration reprocessing plants operate at half capacity and that the large reprocessing plant is not built. Consequently, approximately 9 tons and 22 tons of separated plutonium would be produced cumulatively by 2030 and 2040, respectively—still several times its current inventory of military plutonium for weapons, which is about 2.9 tons.

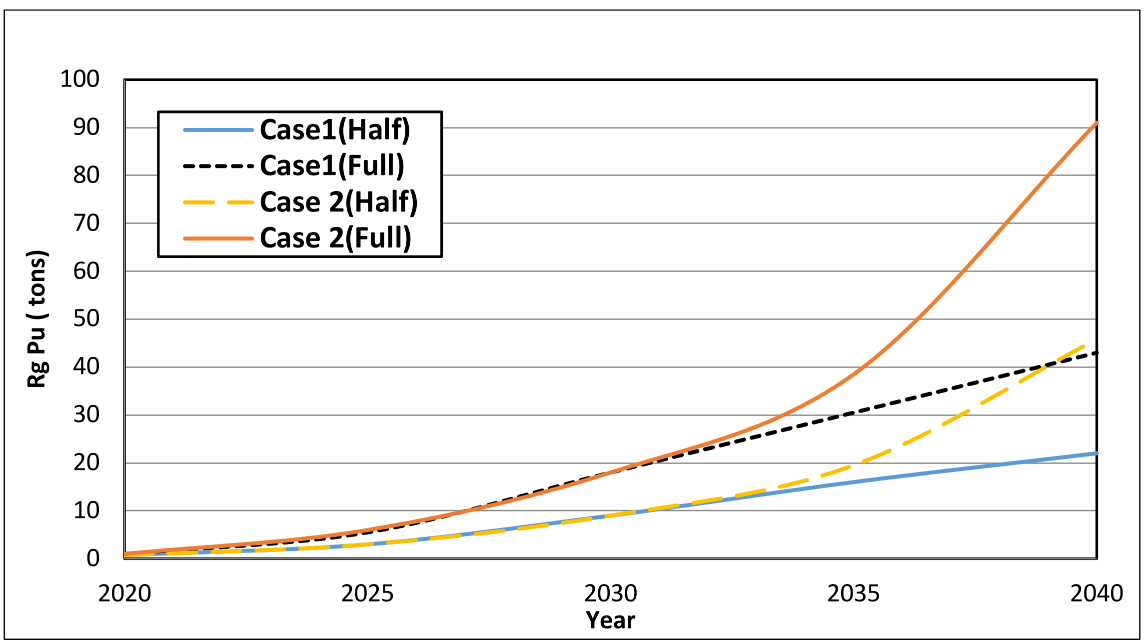

Figure 3: Projections of cumulative plutonium separated from PWR spent fuels from 2020 to 2040

Cumulative PWR Plutonium Used by Fast Reactors

Projections of how much separated plutonium from PWR spent fuel will be used in China's fast-reactor programs are based on following assumptions: (1) CEFR continues using HEU fuel until 2024, then uses MOX fuel from 2025 through 2040. Its initial core requires plutonium of 150 kg,[20] and the replacement is about 150 kg plutonium/year.[21] (2) The first CFR-600 is commissioned in 2023 and uses Russian-supplied HEU for the first seven years.[22] It starts in 2030 using MOX fuel supplied from the 200 tons-per-year demonstration reprocessing plant. It requires a 2-ton initial core inventory and a 1 ton replacement each year.[23] CIAE fast-reactor experts suggest a beginning recycling time of 2 years for the MOX-fueled FBR.[24] If so, one CFR-600 would need an inventory of about 4 tons of PWR plutonium. However, as a conservative estimate, the recycling time is assumed to be 5 years here. Thus, the CFR-600 would need an inventory of 7 tons of PWR plutonium. (3) The second CFR-600 starts construction by the end of 2020 and becomes operational in 2026. Like the first CFR-600, it starts using MOX fuel in 2030 with the same assumptions.

Consequently, as a high case of plutonium use, assuming the CEFR and the two CFR-600 fast reactors operate at full design capacity as discussed above, approximately 4.9 tons and 16.4 tons of separated plutonium would be used cumulatively by 2030 and 2040, respectively, as shown in Figure 4. In a low-use case, assuming the CEFR and two CFR-600 fast reactors operate at half of their designed capacity, approximately 4.5 tons and 10.3 tons of separated plutonium would be used cumulatively by 2030 and 2040, respectively.

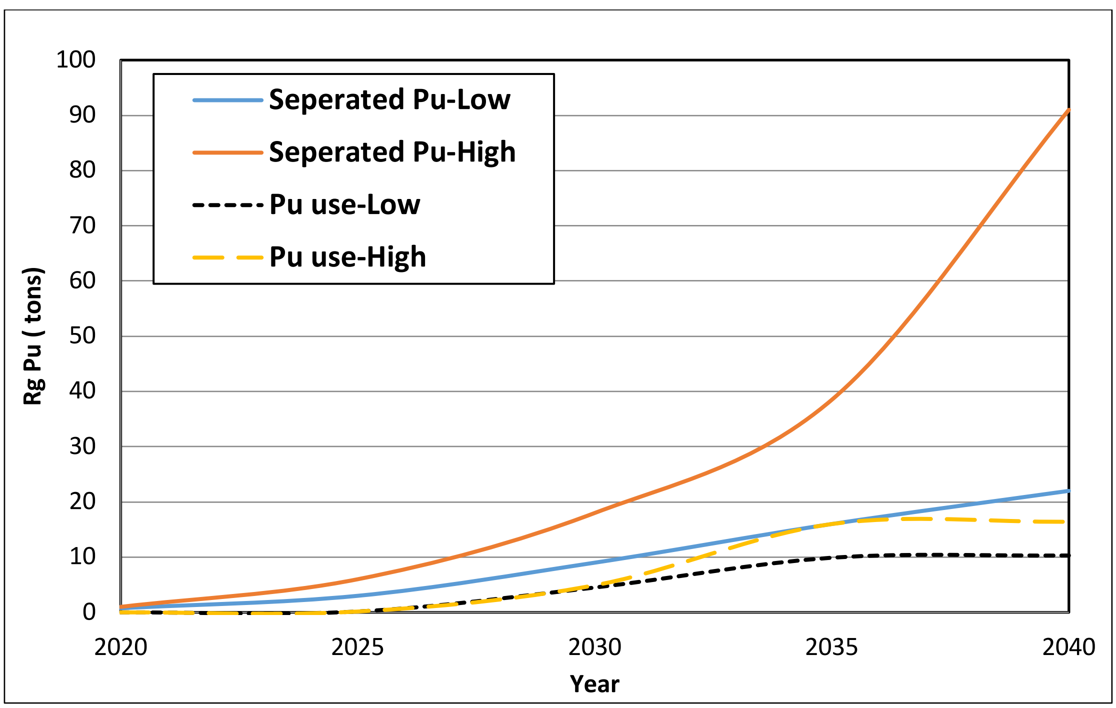

Figure 4: China's projected cumulative PWR plutonium produced and used in fast reactors 2020-2040. The figure shows clearly even the low case of plutonium produced could be large enough to meet the planned fast reactor programs through 2040.

It should be noted that, as shown in Figure 4, even the low case of separated plutonium production is large enough to meet the high case of plutonium use for FBRs. Thus, it would make no sense for China to build an 800 tons-per-year reprocessing plant in the near future.

Figure 5 shows a projection of China's stockpile of separated PWR plutonium from 2020 to 2040. The high plutonium-stockpile case (labelled "Plutonium surplus-High") assumes the high scenario of separated plutonium production ("Separated Pu-High" in Figure 4) minus the low-use case of plutonium ("Pu use-Low in Figure 4). The low plutonium-stockpile case ("Plutonium surplus-Low" in Figure 5) assumes the low scenario of separated-plutonium production ("Separated Pu-Low" in Figure 4) minus the high-use case of plutonium ("Pu-use-High" in Figure 4). As shown in Figure 5, if China builds an 800 tons-per-year reprocessing plant in 2035 as discussed, it could amass a stockpile as large as around 80 tons of separated plutonium by 2040.

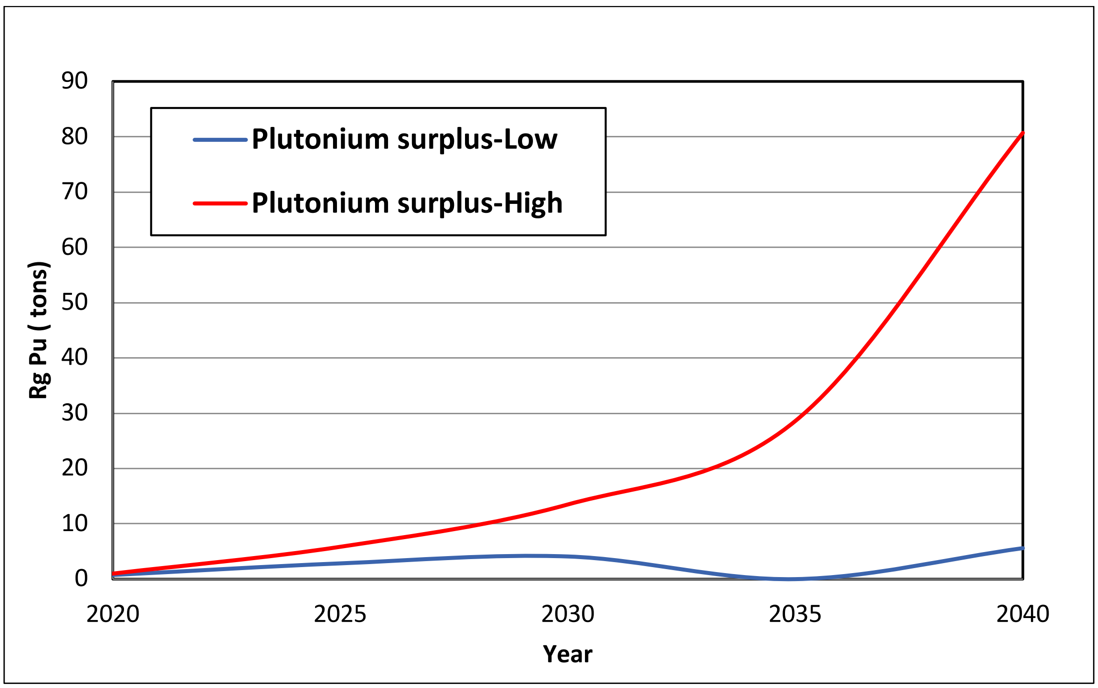

Figure 5: Projections of China's stockpile of separated PWR plutonium from 2020 to 2040.

Most likely, China will have as large a stock of reactor-grade plutonium as Japan and France have. China has long worried about Japan's reprocessing and recycling programs, which could be used in weapons if needed,[25] but China's own programs would only encourage others to follow the same path. Further, recently some experts on arms control and nonproliferation in Western have raised concerns about the possibilities that China could use its plutonium recycling programs for nuclear weapons purpose, including using the reactor grade plutonium in its FBRs to produce weapon-grade plutonium in the breeder blankets.[26]

China needs to keep its plutonium recycling programs more transparent including reporting timely its stockpile of civilian plutonium as did before 2016. China should learn from the experiences of other countries that have prematurely launched large reprocessing programs with the expectation that the commercialization of breeder reactors would follow—but did not. China has no convincing rationale for rushing to build commercial-scale reprocessing facilities or plutonium breeder reactors. China should postpone the large reprocessing-plant project, and take an interim-storage approach. Following this approach will give China a substantial opportunity to carefully develop a long-term policy for the nuclear fuel cycle.

NOTES AND REFERENCES

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[3] See, China's annual report of civilian plutonium holdings by IAEA from 2010 to 2016 by IAEA: INFCIRC/549/add.7/10--INFCIRC/549/Add.7-16. E.g. https://www.iaea.org/sites/default/files/infcirc549a7-14.pdf; https://www.iaea.org/sites/default/files/publications/documents/infcircs/1998/infcirc549a7-16.pdf.
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[13] See Xu, "Fast Reactor Development for a Sustainable Nuclear Energy Supply in China."
[14] It is reported the reactor generated a total of 5790.4 MWh from 2011-2015, i.e., about 12.06 equivalent operation days. Moreover, based on the described operation in 2014, I estimate that it was about 8.12 equivalent operation days in 2014 (see Yang Hongyi, "Fast Reactors Progress and Cooperation with French," the Second Black End Seminar in Beijing, May 5, 2015.) Thus, it achieved about 3.94 equivalent operation days in 2015. Finally, it was reported the reactor operated for 23 days at 39 MWt in 2016, i.e., about 13.8 equivalent operation days (see, Zhang Donghui, "The Development of Nuclear Energy and FR in China," presentation at the 50th TWG-FR meeting, Vienna, May 15-18, 2017.
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[18] Hui Zhang, "China's Plutonium Recycling 2020-2040: Current Practices and Projected Capacities," Research paper for the Nonproliferation Policy Education Center, forthcoming.
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[20] Xu, "Fast Reactor Development for a Sustainable Nuclear Energy Supply in China," op.cit.
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[25] Hui Zhang, "China Worries about Japanese Plutonium Stocks," Bulletin of the Atomic Scientists, Jun 17, 2014.
[26] Hui Zhang, "China's Plutonium Recycling 2020-2040: Current Practices and Projected Capacities," op.cit.