

# Rethinking Chinese Policy on Commercial Reprocessing

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## ABSTRACT

By 2011 China is operating fourteen nuclear power reactors with installed capacity of 11.88 GWe, and it plans to increase its total nuclear capacity to 70 GWe by 2020. China is seeking to reprocess the civilian spent fuel, and to recycle the plutonium in MOX fuel for its fast breeder reactors. A pilot reprocessing plant with a capacity of 50tHM/a conducted successfully a hot test in December 2010. Meanwhile, China is building a pilot MOX fuel fabrication facility with 0.5 t/a. A larger commercial reprocessing plant and a MOX fabrication plant are expected to be in commission around the year 2025. The China Experimental Fast Reactor (25 MWe) started operation in July 2010. Furthermore, larger commercial FBRs are planned to be commissioned around 2030-2035. This paper will discuss the status of China's nuclear power reactors, breeders, and civilian reprocessing programs. In addition, this paper will examine whether the breeders and civilian reprocessing programs make sense for China, taking into account costs, proliferation risks, energy security tradeoffs, health and environmental risks, and spent fuel management issues.

## China's Current Nuclear Program

China has 14 reactors in operation with an aggregate installed capacity of about 11.88 GWe, which accounts for less than 2 % of China's electricity generation (see Table 1). In addition, 27 reactors capable of producing a total of 29.89 GWe are under construction. China officially plans to increase its total nuclear capacity to 40 GWe, as well as have additional reactors with a total capacity of 18 GWe under construction by 2020 (about 4% of its total electricity generation).<sup>1</sup> The nuclear industry expects up to a 70 GWe capacity by 2020, a 200 GWe capacity by 2030 and a 400-500 GWe capacity by 2050 (amounting to approximately 15% of its total electricity generation).

China's policy of nuclear development has been changed since 2005 from "moderate development" to "energetic development". The major motivations behind China's ambitious nuclear power program are 1) to increase national energy security through diversifying prime energy supply, thereby reducing concerns about energy resource limitations, and uneven distribution of energy resources; 2) to lessen environmental concerns including air pollution and climate change issues; 3) to raise the level of industrial manufacturing and promote the

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<sup>1</sup> The Mid-Long Term Development Program of Nuclear Power (2005-2020), China's National Development and Reform Commission (NDRC), Beijing, October 2007.

development of science and technology.<sup>2</sup> China expects to realize self-design, self-construction and self-management of its nuclear power facilities by 2020.

In the wake of the Fukushima nuclear accident, the State Council announced on 17 March 2011 that China would suspend approval of all new nuclear power stations, conduct comprehensive safety checks on all existing plants and review all nuclear projects including those under construction. The new safety standards are expected to be released in early 2012. While the NPP development pace has been temporarily slowed down, many Chinese experts still expect China will install up to a 70 GWe capacity by 2020. China's long-term goal of the nuclear expansion will not be changed significantly.

**Table 1: Operating Reactors in China**

Reactors	Capacity (Mwe)	Type	design	Operation
Qinshan I #1	300	PWR	China	1991.4
Daya Bay #1	984	PWR	Franatom	1994.2
Daya Bay #2	984	PWR	Franatom	1994.5
Qinshan II #1	650	PWR	China	2002.4
Qinshan II #2	650	PWR	China	2004.5
Lingao #1	990	PWR	Franatom	2002.5
Lingao #2	990	PWR	Franatom	2003.1
Qinshan III #1	700	Candu	Candu	2002.12
Qinshan III #2	700	Candu	Candu	2003.7
Tianwan #1	1060	VVER	Russia	2007.5
Tianwan #1	1060	VVER	Russia	2007.8
Lingao #3	1086	PWR	China	2010.9
Qinshan II #3	650	PWR	China	2010.10
Lingao #4	1086	PWR	China	2011.9

### China's Plans on Reprocessing

In the mid 1980s, China selected a closed fuel cycle strategy to reprocess spent fuel, and it has recently accelerated its nuclear development in pursuit of this strategy. China plans to recycle the plutonium into fast breeder reactor fuel. The major motivations for China's pursuit of plutonium recycling, as its proponents argue, include benefits such as full utilization of uranium resources, reduced waste repository volume, minimization of radioactive toxicity, safe disposal of radioactive waste, and reduced burden of spent fuel at reactor pools.<sup>3</sup>

<sup>2</sup> The Mid-Long Term Development Program of Nuclear Power (2005-2020), op.cit.

<sup>3</sup> See, e.g. Xu Mi, Fast Reactor Development for a Sustainable Nuclear Energy Supply in China, presentation at Harvard-Tsinghua Workshop on Nuclear Energy and Nuclear Security, March 14-15,

China began construction of a multi-purpose pilot reprocessing plant at Jiuquan nuclear complex in July 1997. This plant has an initial production capacity of 50 tHM/a (can be expanded to a capacity of 100 tHM/a). China conducted successful a hot test in December 2010. The primary purposes of this pilot reprocessing plant are for R&D of future reprocessing technologies and for providing MOX fuels for the China Experimental Fast Reactor (CEFR). However, many scientists argue that China still have a long way to go for a larger-scale commercial reprocessing plant.

In recent years, the China National Nuclear Corporation (CNNC) has been negotiating with France's Areva on building a commercial reprocessing plant (800 tHM/a). As it would likely take about 15 years to build such a large reprocessing plant, early commissioning of the plant would probably take place around 2026. Recently the CNNC has planned to build a medium-scale commercial reprocessing plant (200 tHM/a) by 2020 and a larger one (800 tHM/a) between 2025 and 2030.<sup>4</sup>

Meanwhile, a MOX fuel fabrication plant is planned to be in commission at the same time as the reprocessing plant. A pilot MOX fuel fabrication plant (with a capacity of 0.5 ton/a) is now under construction. The plutonium for the MOX fuel will come from the pilot reprocessing plant. Chinese nuclear experts also suggest that the separated plutonium from the reprocessing plants be recycled within two years.

### **China's Fast Reactor Programs**

Chinese nuclear experts believe that to install a huge nuclear power capability (about 240GWe or higher) by 2050, the development of FBRs is necessary. They argue that it is impossible to utilize only pressurized water reactors (PWRs) in realizing such an ambitious goal because of the limitation of uranium resources.<sup>5</sup>

China started construction of the CEFR with a power capacity of 25 MWe (65MWt) in May 2000.<sup>6</sup> It is a sodium cooled experimental fast reactor, located about 40 km away from the city of Beijing. The FBR program was listed as National Hi-Tech's "863 program" in 1986. The conceptual design of the CEFR was finished between 1990 and 1992. The construction started in May 2000. The reactor building was completed in August 2002. It had a physics start-up and arrived at its first criticality in July 2010, and had 40% of its full power incorporated to the grid by July 2011. Since then, however, it has been in a status of cold standby. It is expected to be restarted in the mid-2012.

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2010. Beijing, China; Gu Zhongmao, The Sustainable Nuclear Energy Needs Closed Fuel Cycle, presentation at Harvard-Peking University Workshop on Economics of Nuclear Reprocessing, October 15, 2011, Beijing, China.

<sup>4</sup> Zhao Zhixiang, Closed Nuclear Fuel Cycle and Sustainable Development of Nuclear Power in China, presentation at Harvard-Peking University Workshop on Economics of Nuclear Reprocessing, October 15, 2011, Beijing, China.

<sup>5</sup> Xu Mi, Fast Reactor Development for a Sustainable Nuclear Energy Supply in China, op.cit.

<sup>6</sup> See, e.g. Xu Mi, Fast Reactor Development for a Sustainable Nuclear Energy Supply in China. op.cit.

Moreover, the CNNC signed an agreement in 2009 with Russia with an intention to purchase two Russian 800 MWe BN-800 fast breeder reactors.<sup>7</sup> The CNNC also plans to build a few of 800 MWe commerce FBRs by 2030 and a series of commercial FBR by 2032 (see table 2).<sup>8</sup>

**Table 2: China’s FBR Development Strategy**

<b>Reactor</b>	<b>Power (MWe)</b>	<b>Design beginning</b>	<b>Commission</b>
<b>CEFR (I)</b>	<b>20</b>	<b>1990</b>	<b>2010</b>
<b>CDFR (II)</b>	<b>600-900</b>	<b>2007</b>	<b>2018-2020</b>
<b>CCFR (II)</b>	<b>Nx 800-900</b>	<b>2015</b>	<b>2030</b>
<b>CDFBR (III)</b>	<b>1000-1500</b>	<b>2018</b>	<b>2028</b>
<b>CCFBR (III)</b>	<b>1000-1500</b>	<b>2020</b>	<b>2030-2032</b>

However, the world-wide experience of the FBR programs shows no convincing evidence to support China’s ambitious FBR plans. Now only a few FBRs (less than 1 GWe) are operating. The only commercialized FBR—Superphenix—was abandoned in 1998 and is being decommissioned. No commercialized FBR is operating now. The breeder research, development and demonstration funding has declined dramatically between 1974 and 2007. Many scientists doubt the key assumptions of the rationale for pursuing FBR programs.<sup>9</sup>

### **The Economics of Reprocessing**

There is no overall economic assessment of reprocessing and FBRs in China. Some argue that it is impossible to do this because China’s nuclear power development is still at a very preliminary stage. An assessment would have to be done step by step. While there may not be enough data for China to do a comprehensive analysis on the economic costs of plutonium recycling based on its own experiences, the experiences of other countries in regards to reprocessing could serve as a guide.

<sup>7</sup> Communications with Chinese nuclear experts on FBR program, October 2011, Beijing.

<sup>8</sup> Xu Mi, Fast Reactor Development for a Sustainable Nuclear Energy Supply in China. op.cit.

<sup>9</sup> Thomas Cochran, et al., *Fast Breeder Reactor Programs: History and Status*, A research report of the International Panel on Fissile Materials, February 2010. <http://www.ipfmlibrary.org/rr08.pdf>.

Many scientists around the world have argued that the reprocessing option may be much more expensive than the direct disposal option. For example, a study conducted by a Harvard University-based group concludes that reprocessing and recycle (with quite optimistic assumptions) will not be economic until uranium reaches \$360/kgU.<sup>10</sup>

A recent MIT study on the Future of the Nuclear Fuel Cycle also recommends that “For the next several decades, a once through fuel cycle using light water reactors (LWRs) is the preferred economic option for the U.S. and is likely to be the dominant feature of the nuclear energy system in the U.S. and elsewhere for much of this century.”<sup>11</sup>

Based on a preliminary study on costs of Chinese reprocessing for different scenarios,<sup>12</sup> the reprocessing for MOX case is much more costly than that of interim storage case (see table 3). Other countries’ experience also shows that plutonium recycle is much more costly than LWR once-through cycle. Chinese case would have no significant change from others. In practice, China’s pilot reprocessing plant costs over 2 billion Yuan (around 300 million US dollars) and takes over 20 years from construction to a successful hot test. The 800 t commercial plant would be a few tens billion dollars. In short, before Beijing makes a final decision to build a larger commercial reprocessing plant, it should do carefully its own assessment of the cost of plutonium recycle.

**Table3: Accumulative Costs for Spent Fuel Management Scenarios (2008 US \$M)**

Scenario	0% discount rate	5% discount rate
<b>Scenario I: No reprocessing Chinese reactors</b> Assuming: send all spent fuel that they cannot store onsite to off-site interim dry or wet storage	319	124
<b>Scenario II: recycling separated plutonium as MOX fuel for LWRs</b> Assuming: 1) during 2010-2024, start reprocessing 50 tons/year; manufacturing MOX 0.5 tons/year; 2) During 2025-2034, start reprocessing 800 tons/year in 2025; recycling separated Plutonium as MOX fuel for LWRs with a capability of 40 tons/year	20264	7274

<sup>10</sup> Bunn, Matthew, Steve Fetter, John Holdren, and Bob van der Zwaan. *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel*. Cambridge, Mass.: Report for Project on Managing the Atom, Belfer Center for Science and International Affairs, Harvard Kennedy School, December 2003. <http://belfercenter.ksg.harvard.edu/publication/2089/>.

<sup>11</sup> MIT, *the Future of the Nuclear Fuel Cycle*, 2011.

[http://web.mit.edu/mitei/research/studies/documents/nuclear-fuel-cycle/The\\_Nuclear\\_Fuel\\_Cycle-all.pdf](http://web.mit.edu/mitei/research/studies/documents/nuclear-fuel-cycle/The_Nuclear_Fuel_Cycle-all.pdf)

<sup>12</sup> See details: Yun Zhou, China’s Spent Fuel Management: Current Practices and Future Strategies, *Energy Policy*, 39(2011)4360-4369.

## China's Uranium Resource and Energy Security Issues

One major motivation for plutonium reprocessing and recycling in China is “saving uranium” to increase the domestic supply of uranium. However, such an argument could only make sense if China's energy system becomes much more dependent on nuclear energy and worldwide uranium resources become depleted or at least prohibitively expensive. However, this is not likely in the foreseeable future.

The Chinese Atomic Energy Authority (CAEA) estimated that China had about 100,000 tU of uranium resources (<\$130/kgU) in 2007.<sup>13</sup> The Red Book 2009 reported that newly discovered uranium resources during 2007 and 2008 amount to a total of about 71,400 tU categorized as reasonable assured resources and inferred resources.<sup>14</sup> Regarding China's consumption of uranium, based on current estimates, China could use around 50% of its known uranium resources (171,400 tons) by 2020 and possibly deplete them within a few decades.

However, based on recent studies, China would have a huge potential of uranium resources (up to 2 million tons of uranium deposited).<sup>15</sup> China's uranium resource supply could be enough for the near-term, secure for the mid-term, and big potential in the future.

The consideration of Chinese domestic uranium reserves should not be the sole determinant in opting for a closed fuel cycle. China's nuclear power program should also depend on the international uranium market. In practice, China has already developed a uranium resource strategy, combining “domestic production, overseas exploitation, and the world trade of uranium.” Meanwhile, China's nuclear industry is actively participating in exploration and mining abroad. Consequently, China's exploration and investment in Domestic and overseas uranium resource should not constrain China's development of nuclear energy for next several decades.

The Red Book “Uranium 2007: Resources, Production and Demand” concludes that “based on the 2006 nuclear electricity generation rate and current technology, the identified resource base will remain sufficient for 100 years.”<sup>16</sup> The new MIT Study also concludes that “there is no shortage of uranium that might constrain future commitments to build new nuclear plants for much of this century...”<sup>17</sup>

In practice, the amount of recoverable uranium would increase along with uranium prices. Total world uranium resources are dynamic and related to commodity prices, meaning that with higher prices, the greater the level of exploitation and exploration, leading to more availability. Moreover, if uranium in the oceans (4500 Mt worth) can be extracted, it can support the nuclear energy system for many centuries.

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<sup>13</sup> CAEA, China's Uranium Resource, Production and Demand, 2007.

<sup>14</sup> *Uranium 2009: Resources, Production and Demand*, OECD, International Atomic Energy Agency, July 2010.

<sup>15</sup> Communications with a Chinese nuclear expert on Uranium resources, October 2011, Beijing.

<sup>16</sup> *Uranium 2007: Resources, Production and Demand*, OECD, International Atomic Energy Agency, June 2008.

<sup>17</sup> MIT study on the Future of the Nuclear Fuel Cycle, op.cit.

Finally, if China becomes seriously concerned about the depletion of its uranium supply, it can easily and inexpensively establish a “strategic” uranium stockpile. This would be a much less expensive strategy than a reprocessing and plutonium recycling strategy. For instance, the costs for importing and storing three months’ oil supply could buy enough natural uranium to supply a 40 GWe capacity for 25 years.

## Spent Fuel Management

One main motivation for the rush to develop reprocessing is to reduce the burden of spent fuels storage at reactor sites. The AR spent fuel pools of Qinshan1 and Daya Bay reached full capacity around 2002 and 2003 respectively. Since September 2004, spent fuels have been transported to the Jiuquan Spent Fuel Wet Storage Pool which is located close to the pilot reprocessing plant. The Jiuquan Wet Storage Pool, with a capacity of 550tHM, was completed in November 1994 and started receiving spent fuel in 2004.

Meanwhile, the Beishan area, a desert area in Gansu, was pre-selected for a deep geological disposal site for HLW from reprocessing. This huge area would be able to store all of the HLW resulting from China’s future operation of its nuclear reactors. Also, an underground laboratory is planned to be established by 2020. The repository would be operational by 2050.

Based on the installed capacity of operating reactors (as shown in Table 1) and the projection of 60 GWe by 2020, it is estimated that with a wet pool capacity of 1000 tHM, China would not need additional spent fuel storage until 2025, and with a wet pool capacity of 3000 tHM, China would not need additional spent fuel storage until 2035. In short, China will have little pressure to reduce the burden of spent fuel storage issue in the near future.

Practically, China could take measures in delaying the requirement for additional storage, including re-racking spent fuels at existing reactor pools, building larger pools for new reactors, and on-site dry cask storage. Eventually, as one study shows, dry cask storage, which would allow for decades of cheaper and safer storage, would be the most cost-effective approach to spent fuel management.<sup>18</sup>

Nuclear experts who advocate processing and plutonium recycling in China argue that reducing the volume of highly radioactive wastes is one of the key tasks of the closed cycle. However, it should be noted that the loading of a Yucca Mountain-like repository is constrained by temperate limits (due to the high decay heat from spent fuel) and not by physical volume. In practice, the increasing drift loading for MOX case is of very small benefit, only a factor of 1.087. In the case of regular reprocessing, the drift loading could be increased by a factor of 5.<sup>19</sup> However, in any scenario, China would require a permanent waste repository for the geological disposal of high level waste (either spent fuel or VHLW from reprocessing). Thus, the key remaining question is

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<sup>18</sup> See, e.g. Matthew Bunn, et al., *Interim Storage of Spent Nuclear Fuel—A Safe, Flexible, and Cost-Effective Near-Term Approach to Spent Fuel Management*, A joint report from the Harvard University Project on Managing the Atom and the University of Tokyo Project on Sociotechnics of Nuclear Energy, June, 2001.

<sup>19</sup> Rold Wigeland, et al., *Spent Nuclear Fuel Separations and Transmutation Criteria for Benefit to a Geologic Repository*, WM 04 Conference, February 29 - March 4, 2004, Tucson, AZ.

whether space for such a repository is limited or not. In fact, China's Beishan area appears to have an extremely large potential for storage capacity, and the Chinese government would have no difficulty in procuring additional sites for storage if necessary.

## **Nuclear Proliferation Concerns**

Given that reactor-grade plutonium is weapons-usable, and separated plutonium – unlike “self-protecting” spent fuel – is easily taken, the international community has long been concerned about the proliferation risks of plutonium recycling systems.

China currently has a smaller military stockpile of plutonium (1.8 tons) produced by its two plutonium production reactors.<sup>20</sup> However, this smaller military stockpile will be soon surpassed by its civilian inventory of separated plutonium as China's commercial reprocessing plants operate. Following the operation of its pilot reprocessing plant on December 21, 2010, in its annual INFCIRC/549 report of civilian plutonium holdings for 31 December 2010, China declared a stock of 13.8 kg of separated plutonium “in product stores at reprocessing plants.”<sup>21</sup> Once the pilot reprocessing plant is fully operational, it will separate 0.5-1 ton of plutonium per year. Moreover, when a commercial-scale reprocessing plant with a capacity of 800 tons per year is built, it 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. Thus, the costs and burden of safeguards and physical protection would be increased significantly for the Chinese government.

China's plutonium recycling policy could also encourage other non-nuclear weapons states to pursue reprocessing, which could provide a cover for proliferation. While China is concerned about Japan's plutonium program, China's own plutonium reprocessing would make it difficult for China to dissuade others from going down a similar route. Conversely, if China does not pursue reprocessing and recycling, it could set a good example for other countries that are contemplating reprocessing.

## **Conclusions**

To examine whether China should build a large commercial reprocessing plant and fast-neutron reactors in the near term, Beijing should take account the costs, energy security, proliferation risks, health and environmental risks, and spent fuel managements issues.

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<sup>20</sup> See details in: Hui Zhang, “Chapter 7: 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>; Hui Zhang, “China's HEU and Plutonium Production and Stocks,” *Science & Global Security* 19, no. 1, January–April 2011, pp. 68–89, <http://belfercenter.ksg.harvard.edu/files/huizhangSGS2011.pdf>.

<sup>21</sup> *Communication received from China Concerning Its Policies Regarding the Management of Plutonium* IAEA INFCIRC/549/Add.7/10, 8 July 2011. [www.iaea.org/Publications/Documents/Infcircs/2011/infcirc549a7-10.pdf](http://www.iaea.org/Publications/Documents/Infcircs/2011/infcirc549a7-10.pdf).

Other countries' experience shows that plutonium recycling is much more costly and much less safe and secure than LWR once-through cycle. China should do its own assessment of the cost of plutonium recycle.

Known resources of low-cost uranium worldwide are sufficient for this century. China should invest more in improving estimates of its domestic uranium resource. Meanwhile, China should strategize for oversea exploitation and world trade, and uranium stockpiling.

Before the cost and risks of reprocessing and fast breeder technologies are reduced, China should take an interim storage approach, which offers a safe, flexible, and cost-effective near term approach to spent fuel management. This interim storage option will give China a substantial opportunity to carefully develop a long-term policy for the nuclear fuel cycle.