On China's Commercial Reprocessing Policy

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ABSTRACT

China is currently operating eleven nuclear power reactors with installed capacity of 9 GWe, and it plans to increase its total nuclear capacity to 40 GWe by 2020. China is seeking to reprocess the civilian spent fuel, and to recycle the plutonium in MOX fuel for its light water reactors (LWRs) and fast breeder reactors (FBRs). A pilot reprocessing plant with a capacity of 50-100 tHM/a is ready to operate now. A larger commercial reprocessing plant and a MOX fabrication plant are expected to be in commission around the year 2020. Also, the China Experimental Fast Reactor (CEFR), capable of producing 25 MWe of power, will be operating soon. Furthermore, larger commercial FBRs are planned to be commissioned around 2030-2035. This paper will first 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 Nuclear Energy Development

Currently, China has eleven reactors in operation with an aggregate installed capacity of about 9.068 GWe, which accounts for about 1.27% of China's electricity generation (see Table 1). Also, eight reactors capable of producing a total of 7.9 GWe are under construction (see Table 2). 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).[1] The nuclear industry expects up to a 60 GWe capacity by 2020 and a 160 GWe capacity by 2050 (amounting to approximately 10% of its total electricity generation).[2]

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[1] The Mid-Long Term Development Program of Nuclear Power (2005-2020), China's National Development and Reform Commission (NDRC), Beijing, October 2007.
[2] See, e.g., Zhu Xuhui, Nuclear Power Development in China and Nonproliferation, presentation at the 11th PIIC Beijing Seminar on International Security:Building a Harmonious World of Stability and Win-Win, Qingdao, China, October 26-30 , 2008.

China's recent policy of nuclear development has been changed 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 development of science and technology.[3] China expects to realize self-design, self-construction and self-management of its nuclear power facilities by 2020.

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	2004.3
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	2003.11
Tianwan #1	1060	VVER	Russia	2007.5
Tianwan #1	1060	VVER	Russia	2007.8

[3] The Mid-Long Term Development Program of Nuclear Power (2005-2020), op.cit.

Table 2: Reactors under Construction in China

Reactors	Capacity (MWe)	Type	Note
Lingao II #1	1080	PWR	Start construction 2005.12, to operate in 2010
Lingao II #2	1080	PWR	Start construction 2005.12, to operate in 2010
Qingshan II ext #1	650	PWR	Start construction 2006.4, to operate in 2011
Qingshan II ext #2	650	PWR	Start construction 2006.4, to operate in 2011.
Hongyanhe I	4 x 1110	PWR	Under construction
Total	7900		

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. The United States' discussion on GNEP and potential resumption of its reprocessing program within the last few years have greatly encouraged many Chinese experts in pushing the government to speed up its plutonium recycling program. China plans to recycle the plutonium into LWR MOX fuel and 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 cost of mining, milling, and enrichment, provision of MOX fuel, development of FBRs, reduced energy security concerns, reduced waste repository volume, minimization of radioactive toxicity, safe disposal of radioactive waste, and reduced burden of spent fuel at reactor pools.[4]

China began construction of a multi-purpose reprocessing pilot plant at Lanzhou nuclear complex in July 1997. This project was approved in July 1986. This plant had an initial production capacity of 50 tHM/a, which was later improved to a capacity of 100 tHM/a. This plant began receiving spent fuels from Daya Bay reactors in September 2004. In October 2004, the water test of the facility was conducted. This pilot plant is now fully operational. The primary purposes of this pilot reprocessing plant were for R&D of future reprocessing technologies for LWR-MOX/FBR and for reprocessing spent fuels from research reactors.

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4 See, e.g. Renkai Zhao, et al., *The Energy Technology Area Research Progress of the National 863 Programme*, The Atomic Energy Press, Beijing, 2001; Mi Xu, "The Role of the Nuclear Power in China," Presentation at Conference of International Engineering, November 2000, Beijing, China.

Moreover, a commercial reprocessing plant (800 tHM/a) is planned to be in commission around 2020 at the Lanzhou Nuclear Complex. While preliminary work such as site selection has already begun, construction has not yet started. As it would likely take about 15 years to build such a large reprocessing plant, early commission of the plant would probably take place around 2025. 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 160GWe 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. The roadmap of China's nuclear energy will follow three stages, i.e., PWR---FBR---Fusion reactor.

China started construction of the China Experimental Fast Reactor (CEFR) with a power capacity of 25 MWe (65MWt) in May 2000.[5] 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. In 1995, the CEFR project was approved and its preliminary design was finished within the next two years. The detail design was conducted from 1998 to 2003. The reactor building was completed in August 2002. It is planned to have a physics start-up and its first criticality in June 2009, and have 40% of its full power incorporated to the grid by December 2009.

Moreover, China plans to build a 800 MWe demonstration fast breeder reactor by 2020, 2-3 x 800 MWe commerce FBRs by 2030, and a series of commercial FBR by 2035.[6]

The Economic Costs of Plutonium Recycling

While many experts around the world have come to the realization that reprocessing and plutonium recycling is more expensive than a once-through cycle with direct disposal of spent fuel for at least the next several decades, is China's plutonium recycling rational in the view of economic costs?

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

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[5] See, e.g. Xu Mi, China Fast Reactor Technology Development: Recent Status and Future, presentation at the 5th Tsuruga International Energy Forum, Tsuruga, Japan, June 28-29, 2006.
6 See, e.g. Zhu, Nuclear Power Development in China and Nonproliferation, op. cit.

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.

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 concluded that “reprocessing and recycling plutonium in existing light-water reactors (LWRs) will be more expensive than direct disposal of spent fuel until the uranium price reaches over $360 per kilogram of uranium (kgU)…”

Specifically focusing on China’s case in regards to plutonium recycling, an early study on a comparison of costs between reprocessing for MOX fuel fabrication and direct disposal of spent fuel concluded that with the current circumstances, at discount rate of 5%, the costs of the MOX fuel reprocessing option would be over three times greater than that of the direct disposal option.[7] Even across a wide range of different assumptions concerning the specific prices for reprocessing and MOX fabrication services, uranium prices would have to increase several times for plutonium recycling to be as economically viable.

Moreover, the costs of recycling plutonium in breeders utilizing current technology, which is dependent upon the capital cost of breeders (generally much higher than that of LWRs) and the cost of fabricating and reprocessing breeder fuel and the like, would be much higher than that of the direct disposal option. For example, the Harvard study showed that reprocessing and recycling plutonium in fast-neutron reactors with an additional capital cost, compared to installing new LWRs of 200/kWe, will not be as economically competitive until the price of uranium reaches to $340/kg, given their central estimates of the other parameters.

Energy Security Considerations

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.

Even if China’s ambitious nuclear power plan came to full fruition, nuclear energy would only provide about 10% of China’s total electricity generation and only a few percent of primary energy demand. Regarding China’s consumption of uranium, based on current estimates, China could use around 70% of its known uranium resources (70,000 tons) by 2020 possibly deplete them within a few decades. However, based on recent reports, China has potentially large unknown uranium resources, and China’s uranium resource supply could be enough for the near-term, secure for the mid-term, and big potential in the future.

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7 Hui Zhang, “Economic Aspects of Civilian Reprocessing in China,” in *Proceedings of the INMM 42nd Annual Meeting*, Northbrook, Illinois, 2001.

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. Moreover, unlike oil and natural gas resources which are fairly limited to certain geographical locations, sources of uranium are diverse both geographically and politically, and collusion to raise prices and/or limit supplies would be unlikely.

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."[8] 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, in the case of nuclear growth in the future, it is estimated that current uranium resources at acceptable prices will continue to supply reactors with once-through cycles throughout the 21st century, and if uranium in the oceans (4500 Mt worth) can be extracted, it can support the nuclear energy system for many centuries.

Finally, if China becomes seriously concerned about the depletion of 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. Also, the energy systems based on plutonium recycling could potentially cause disruption in the energy supply, since such systems are more complex and error prone than the once-through systems,[9] and thus could lead to a shutdown of nuclear power.

Spent Fuel and High-Level Waste 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 Lanzhou Spent Fuel Wet Storage Pool which is located close to the pilot reprocessing plant. The Lanzhou Wet Storage Pool, with a capacity of 550tHM, was completed in November 1994 and started receiving spent fuel in 2004. Reportedly, storage capacity was to be increased further by another 550tHM within a ten year period starting in the year 2000. Thus, China would have a central storage capacity of 1100tHM by around 2010. A cooling time of five years is required for the spent fuel.

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

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[8] Uranium 2007: Resources, Production and Demand, OECD, International Atomic Energy Agency, June 2008.

9 Lawrence Lidsky, Marvin Miller, "Nuclear Power and Energy Security: A Revised Strategy for Japan," Science *and Global Security*, 10:127–150, 2002.

the HLW resulting from China's future operation of its nuclear reactors. Also, an underground laboratory is planned to be established by 2020. The construction of the repository would be finished sometime between 2030 and 2040, and VHLW disposal would be completed around 2050.

Based on the installed capacity of operating reactors (as shown in Table 1), reactors under construction (as shown in Table 2), and the projection of 40 GWe by 2020, it is estimated that with a wet pool capacity of 1100 tHM by 2010 (as planned), China would not need additional spent fuel storage until 2020. 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, ship spent fuels between pools at the same NPP site, 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.[10]

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. [11] 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 whether space for such a repository is limited or not.

One major motivation for US reprocessing and recycling (under the Advanced Fuel Cycle Initiative or GNEP) is the potential increase in utilization of space in a geologic repository like Yucca Mountain (legislation limits the loading capacity for Yucca Mountain to 70,000 tons and it would be too difficult to get a second site). Despite such a benefit, Congress is now ending the reprocessing program. However, it should be noted that China does not suffer from similar legislated limitations. 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.

A Discussion of HLW Radiotoxicity

Proponents of plutonium recycling argue that it can significantly reduce the long-term hazard of buried high-level wastes. There are still some questions about this argument. For instance, while current P&T programs focus on removing and destroying all actinides from spent

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[10] 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.

[11] 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..

fuels, performance assessments of the repository sites at Yucca Mountain in the US and at Olkiluoto in Finland show that long-lived fission products, such as Tc-99 and I-129, are more important than most actinides as sources of long-term exposure risk.[12] Furthermore, P&T studies have yet to show that it can deal effectively with these fission products. Moreover, the technology is not yet available to completely remove all of these actinides, and any such systems currently under consideration would significantly increase the economic cost of nuclear energy.

In addition, the short-term costs of P&T activities are significantly high. It is believed that plutonium reprocessing and recycling will increase radiation exposure to both workers and the public, as well as increase accident risk. Also, it will generate additional categories of waste that increase the waste-management burden. Consequently, nuclear decision-makers would face the task of having to balance the long-term benefits of waste partitioning and transmutation with the increased short-term health, safety, environmental, and security risks involved. Based on a MIT (2003) study, it seems unlikely that on the basis of waste management considerations alone that the benefits of advanced fuel cycle schemes featuring waste partitioning and transmutation will outweigh the attendant risks and costs. Furthermore, many experts within the scientific and technical community are highly confident that the geological disposal approach is capable of safely isolating nuclear waste from the biosphere for as long as it poses significant risks.

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's plutonium recycling policy could 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

Based on current estimates of the economic viability of plutonium reprocessing, as well as China's various concerns about energy security, management of spent fuels, environmental issues, and nuclear proliferation, China does not need to pursue a reprocessing program in the foreseeable future. China should take an interim storage approach which offers a safe, flexible, and cost-effective near term approach to spent fuel management.[13] While the debates on permanent options for the management and disposal of spent fuel and nuclear waste are still continuing worldwide, the interim storage approach leaves open all the options, allows time for technology to develop further, and gives China the best opportunity to clearly and comprehensively evaluate the alternatives.

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12 John Deutch, et al., *The Future of Nuclear Power: An Interdisciplinary MIT Study*, MIT 2003.
13 See, e.g. Bunn, et al., *Interim Storage of Spent Nuclear Fuel—A Safe, Flexible, and Cost-Effective Near-Term Approach to Spent Fuel Management*, op.cit.