The United States and China: Making Nuclear Energy Safer

Jane Nakano
Fellow, Energy and National Security Program
Center for Strategic and International Studies

July 2013

Introduction

Since the beginning of this century, growing concern over climate change has pushed nuclear energy to the forefront of energy policy considerations across the world. The enormous growth in China's energy demand over the last decade has made nuclear energy expansion an attractive option to address the country's growing dependence on energy imports. What's more, as a zero-carbon form of power generation, nuclear offers the simultaneous benefit of reducing reliance on coal and addressing rising concerns with environmental pollution and climate change. With the remarkable pace and scope of its domestic nuclear power program, China has quickly become a formidable force in the global nuclear energy industry. with the remarkable pace and scope of its domestic nuclear power program expansion. At the beginning of 2011, roughly 40 percent of reactor construction around the world was taking place in China, and it is poised to become the largest market in the coming decades.

Hope of a global nuclear renaissance within some quarters, however, has evaporated since the nuclear power disaster in Fukushima, Japan in March 2011. The Fukushima accident had varying degrees of impact on nuclear power programs around the world, including that of China. With the exception of a few advanced economies with slower energy demand growth, the overall response from governments was not to scrap or severely limit nuclear energy in their respective national energy mix. Those countries, such as Germany, that wanted to move to a post-nuclear energy strategy seized the crisis to push forward. Those that wanted to expand nuclear power as a matter of domestic energy strategy were not going to abandon it because of one accident. Ultimately, Fukushima's effect on global nuclear power programs was somewhat neutral—it neither set them back for decades nor boosted the prospects of a renaissance.

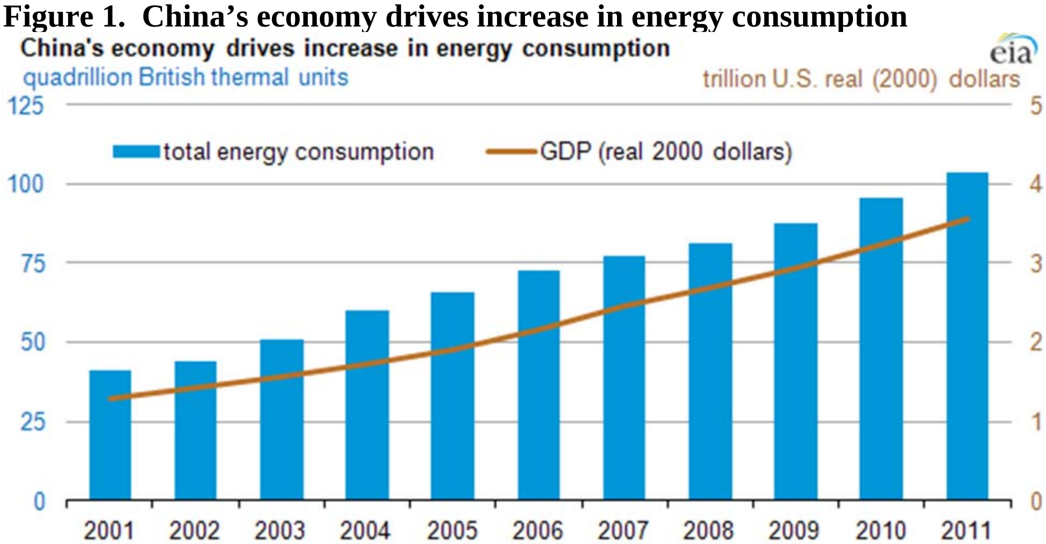
In the case of China, its leadership decided to continue nuclear power expansion. But Fukushima had an undeniable effect on raising China's concern over nuclear safety, just as it had also triggered a wave of safety inspections and prompted reevaluation of nuclear safety and accident mitigation capabilities around the world. What are the key effects of Fukushima on China's nuclear energy plans and programs? Specifically, what efforts exist to address safety-related concerns in the context of the phenomenal pace of nuclear development in China? Moreover, what opportunities exist for China and the United States to collaborate on nuclear safety? The US nuclear industry has a wealth of operational experiences but is in decline due to stagnant domestic demand while China's growing nuclear reactor fleet is short of human capital with rich operational experiences. These contrasting but complementary profiles bring synergies to strengthen bilateral cooperation in the area of nuclear safety.

This paper briefly describes the historical and domestic energy context in which the Chinese nuclear energy program has been developing in recent years. This background is followed by a review of the key changes to China's nuclear power program since Fukushima, including capacity growth targets, safety guidelines, and technology choices. The paper concludes by examining China's civilian nuclear-related institutional capacity, including regulatory conditions and human resources. It also expands on safety related discussions to highlight the current scope of bilateral engagements between the United States and China and the prospect for future expansion of such engagements.

Civilian nuclear power in China: from low base to dramatic expansion

China's robust energy demand, driven by continued economic and population growth, as well as massive urbanization trends of the last decade has elevated nuclear energy—along with renewable energy and natural gas—as a key energy source. For example, between 2001 and 2010, China's energy consumption grew at three times the rate of the previous decade.[1] Over the next decade, China's primary energy consumption is expected to continue growing although it is forecast to begin slowing down beyond 2020.[2] According to the International Energy Agency (IEA), China's demand for energy is expected to account for roughly one-third of total global energy demand growth and nearly a quarter of total global energy demand by 2035.[3]

Figure 1. China's economy drives increase in energy consumption



Source: US Energy Information Administration, September 2012

In China's energy mix, coal is by far the dominant fuel and its predominance isn't likely

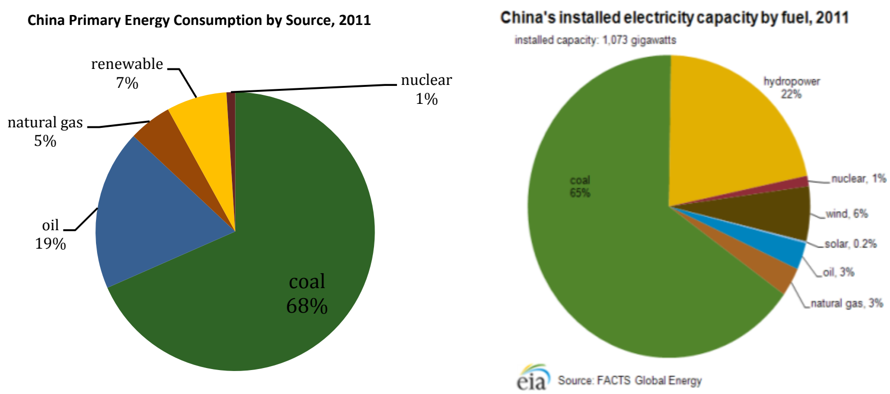
[1] National Bureau of Statistics of China, *China Statistical Yearbook 2012, (*section 7-2 Total Consumption of Energy and Its Composition—*no page number available)*

[2] BP*, Energy Outlook 2030*, p. 46.

[3] International Energy Agency, *World Energy Outlook 2012*, p. 58.

to wane in the foreseeable future (see Figure 2). For example, nearly 70% of China's primary energy consumption and its electricity needs are met by coal.[4] In contrast, nuclear energy plays a miniscule role in the total energy mix. With an installed capacity of just 13 gigawatts (GW), nuclear capacity now constitutes only 2% of total generation capacity.[5]

Figure 2: China's energy mix and installed capacity by fuel type, 2011



Source: National Statistical Bureau

Consequently, reducing reliance on coal is a priority in China's broad energy strategy. As a technologically proven and relatively cheap source of electricity, nuclear energy has come to play a central role in China's plan to diversify its fuel mix away from coal. Although the Chinese government approved the country's first nuclear power plant decades ago in 1982,[6] the sector only began to see dramatic acceleration during the 10th Five-Year Plan (FYP, 2001-2005), when China launched a concerted expansion of its nuclear sector and constructed four reactors.[7] For a country whose civilian nuclear program took off only in the middle of the last decade, China has a remarkably ambitious expansion plan.

That ambition was captured in the Medium- and Long-Term Nuclear Power Development Plan of 2007, which called for 40 GW of installed capacity by 2020, or about 5% of the total energy mix.[8] One of the policy drivers for backing nuclear was the mandatory 20 percent energy intensity reduction target in the 11th FYP (2006-2010), which provided momentum for developing clean energy sources such as nuclear power. Similarly, the 12th FYP (2011-2015) also includes several, arguably stronger, policy drivers that supports nuclear development. Specifically, this FYP calls for a 16% reduction in energy intensity, raising non-fossil energy to 11.4% of total primary energy use, as well as a 17% reduction in carbon intensity. Beijing's stepped up efforts to reduce energy and carbon intensity made nuclear energy an industrial darling showered with

---

[4] US Energy Information Administration, *Country Analysis Brief—China*, last updated: September 4, 2012.

[5] China Nuclear Energy Association, *Nuclear Power Operation Status for the First Quarter of 2013*, June 2013, p. 1. (2013 *nian di yi ji du he dian yun xing qing kuang*)

[6] Bo Kong, "Civil Nuclear Energy Development in China and U.S.-China Nuclear Cooperation," presentation at Brookings Institution seminar, Washington, D.C., Sept. 17, 2010.

[7] World Nuclear Association, *Nuclear Power in China,* updated April 30, 2013.

[8] World Nuclear Association, *Nuclear Power in China*, updated September 2011.

strong policy support and state financial largess. It certainly did not hurt that Zhang Guobao, a long-time energy policymaker and the founding head of the National Energy Administration (NEA), was a big proponent of nuclear energy. By then, China already had over a dozen reactors in operation and a preliminary target of 40 GW capacity under the 2007 plan. But leading up to the Fukushima disaster, the Chinese government indicated that up to 86 GW by 2020 and as much as 500 GW by 2050 could be installed in the country.[9]

In addition to strong growth targets, the Chinese government announced in 2010 plans to develop several nuclear power industrial parks that would focus on developing the country's nuclear supply chain as well as training and education.[10] For example, China announced that it would begin developing a nuclear industrial park in Haiyan with a price tag of about $175 billion over ten years.[11] Also, the China National Nuclear Corporation (CNNC) plans to spend up to RMB 500 billion ($81.5 billion) on nuclear power plant construction through 2015.[12]

Finally, as part of its civilian nuclear power program development, China has emphasized building capabilities to establish a fully integrated domestic supply chain—including "indigenous" nuclear fuel fabrication, self-reliance on design, and project management—with the objective of exporting next-generation nuclear technologies to a global marketplace. This is textbook industrial policy similar to what Japan and South Korea had done before, both of which export civilian nuclear technology.

Post-Fukushima development

The Fukushima accident did not fundamentally alter China's strategy for nuclear energy. Although the safety inspections in the aftermath of Fukushima temporarily slowed the pace of new builds and the 2015 target remained at the more realistic 40 GW,[13] the country's White Paper on Energy Policy in October 2012 reaffirmed the central role for nuclear energy in boosting the proportion of non-fossil fuels in the primary energy mix. The White Paper also included plans to "invest more in nuclear power technological innovations, promote application of advanced technology, improve the equipment level, and attach great importance to personnel training."[14]

---

9 World Nuclear Association, *Nuclear Power in China,* updated September 2011.

10 "Construction of Chinese 'Nuclear City' to start," *World Nuclear News*, Aug. 16, 2010, http://www.world-nuclear-news.org/NN-Construction_of_Chinese_Nuclear_City_to_start_soon-1608104.html.

11 "Construction of Chinese 'Nuclear City' to start," *World Nuclear News*, Aug. 16, 2010, http://www.world-nuclear-news.org/NN-Construction_of_Chinese_Nuclear_City_to_start_soon-1608104.html.

12 "CNNC Plans 500B Yuan Investment in Nuclear Power," Capital Vue, Sept. 19, 2010, http://www.capitalvue.com/home/CE-news/inset/@10063/post/1218296.
"CNNC Plans 500B Yuan Investment in Nuclear Power," Yicai, September 26, 2010, http://www.yicai.com/news/2010/09/414423.html.

13 The Information Office of the State Council, *China's Energy Policy 2012*, www.gov.cn/english/official/2012-10/24/content_2250497_5.htm

14 Ibid.

Even as China did not waver on its basic commitment to expanding nuclear energy, it was affected by Fukushima in one important aspect: raising concerns about the safety of its own plants. In the immediate aftermath of the emergency, Beijing in fact responded rather swiftly and decisively. It quickly halted approval of all new, planned reactor construction, a moratorium that also applied to the four approved units scheduled to start construction in 2011.[15] Within a week of the Japanese disaster, Beijing ordered safety inspections of the country's 11 operational reactors and the 26 that were already under construction—without bringing the units off-line or halting construction.[16] These actions gave the government time to digest the lessons from Fukushima, especially with regard to reactor siting, plant layout, and containing radiation release.[17]

Figure 3: Operational nuclear plants in China (as of March 2013)

Status	Name of Nuclear Power Plant		Unit number	Reactor type	Nominal power MW(e)	Starting date	First date of connection to the grid	Commercial operation date
In operation	Qinshan Nuclear Power Plant		01	PWR	310	1985-03-21	1991-12-15	1994-04-01
	Guangdong Daya Bay Nuclear Power Plant	Unit 1 Unit 2	02 03	PWR	2×984	1987-08-07 1988-04-07	1993-08-31 1994-02-07	1994-02-01 1994-05-06
	Qinshan Phase II Nuclear Power Plant	Unit 1 Unit 2 Unit 3 Unit 4	04 05 06 07	PWR	4×650	1996-06-02 1997-04-01 2006-04-28 2007-01-28	2002-02-06 2004-03-11 2010-08-01 2011-11-25	2002-04-15 2004-05-03 2010-10-21 2011-12-30
	Guangdong LingAo Nuclear Power Plant	Unit 1 Unit 2 Unit 3 Unit 4	08 09 10 11	PWR	2×990 2×1080	1997-05-15 1997-11-28 2005-12-15 2006-06-15	2002-02-26 2002-09-14 2010-07-15 2011-05-03	2002-05-28 2003-01-08 2010-09-20 2011-08-07
	Third Qinshan Nuclear Power Plant	Unit 1 Unit 2	12 13	PHWR	2×700	1998-06-08 1998-09-25	2002-11-19 2003-06-12	2002-12-31 2003-07-24
	Tianwan Nuclear Power Plant	Unit 1 Unit 2	14 15	PWR	2×1060	1999-10-20 2000-09-20	2006-05-12 2007-05-14	2007-05-17 2007-08-16
	Ningde	Unit 1	16	PWR	1089	2008-02-18	2012-12-28	
	Hongyanhe	Unit 1	17	PWR	1080	2007-08-18	2013-02-17	
Total	17 units							

Source: Maoxiong Long, China Nuclear Energy Association, March 2013

Two months after Fukushima, Chinese officials called attention to the need to upgrade the country's emergency procedures at nuclear power plants as well as the need to improve coordination among government departments.[18] By fall 2011, the reactor inspections were completed as well. But it took until May 2012 for Beijing to finally approve the reactor inspection report, which illuminated some shortfalls, including a lack of severe accident mitigation guidelines at some nuclear power plants, and called for improvements and remediation by 2015 in 16 areas that mainly concern emergency

15 World Nuclear Association, *Nuclear Power in China*, updated March 2013.
16 At the time of Fukushima accident, 34 reactors had construction approval, including the 26 units already being built. See World Nuclear Association, *Nuclear Power in China*, updated March 2013
17 World Nuclear Association, *Nuclear Power in China*, updated March 2013.
18 United Press International, *China to boost nuclear safety standards*, May 9, 2011.

backup systems, flooding prevention, and earthquake related safety issues.[19]

Many of these concerns on nuclear safety found their way into the 12th FYP, approved around the same time as the reactor inspection report in 2012. It indicated that most Chinese nuclear plants met the current domestic safety regulations and are in line with International Atomic Energy Agency (IAEA) safety standards and requirements.[20] Highlighting the regulatory challenges associated with China's deployment of multiple reactor technologies, designs, and safety standards, the plan recommended an investment of nearly RMB 80 billion ($13 billion) by 2015 to improve safety at both operating and incomplete reactors.[21]

In October 2012, the State Council officially approved the nuclear safety plan, which unequivocally stressed the importance of safety and called for domestic safety regulations to fully incorporate the internationally accepted level of safety standards by 2020.[22] In addition to recommending that older reactors be phased out sooner and the level of nuclear safety related research and development be enhanced,[23] the plan called for no nuclear incidents at or above the International Nuclear and Radiological Events Scale (INES) Level 3 throughout the Chinese civilian nuclear reactor fleet.[24] China has not had nuclear events that exceed Level 2 on the INES—a globally accepted scale used by the IAEA for prompt and effective public communications. For example, the 1979 Three Mile Island nuclear incident in Pennsylvania, which entailed a partial core meltdown with minor levels of radiation release, was considered a Level 5 event on the INES scale.

Finally, with the approval of the new safety plan came the lifting of the moratorium on new reactor construction. However, delays due to the moratorium and a heightened concern for overall safety led the Chinese government to settle on an installed capacity target of 58 GW by 2020, notably lower than what was previously speculated.

Safety under scrutiny: regulations, human capital, and reactor design

---

[19] Report on the Status of Safety Inspections on Civilian Nuclear Facilities across the Country (*Guan yu quan guo min yong he she shi zong he an quan jian cha qing kuang de bao gao*), National Nuclear Safety Administration, National Energy Administration, and China Earthquake Administration, p. 8-9.
[20] Ibid,. p. 4-5.
[21] 12th FYP for Nuclear Safety and Radioactive Pollution Prevention and Vision for 2020, Ministry of Environmental Protection, National Nuclear Safety Administration, National Development and Reform Commission, Ministry of Finance, National Energy Administration, and National Defense Science and Technology Industrial Development Bureau, p. 19, http://haq.mep.gov.cn/gzdt/201210/W020121016305772730116.pdf.
[22] Fayen Wong, China issues nuclear safety blueprint, eyes $13 billion investment, Reuters, October 16, 2012.
[23] Ibid.
[24] 12th FYP for Nuclear Safety and Radioactive Pollution Prevention and Vision for 2020, Ministry of Environmental Protection, National Nuclear Safety Administration, National Development and Reform Commission, Ministry of Finance, National Energy Administration, and National Defense Science and Technology Industrial Development Bureau, p. 7, http://haq.mep.gov.cn/gzdt/201210/W020121016305772730116.pdf.

Concern has been emerging among China's policymakers over the growing gap between this rapid pace of nuclear infrastructure expansion and institutional and personnel capacity needs, such as a regulatory framework and human resources. Although some efforts to address the gap preceded the Fukushima accident, the incident did inspire safety discussions and examination on a larger platform than ever before.

Inadequate legal framework

The first area of concern has been the absence of an atomic energy law in China. Once China embarked upon a strong nuclear power program expansion, the absence of such a law has become a frequent point of discussion by China observers inside and outside the country. An atomic energy law reportedly has been under consideration in China since the 1980s, but it has yet to materialize. A typical atomic energy law governs a country's approach to nuclear energy use, including its research and development, and serves as an important keystone for nuclear program development. The country does, however, have a related 2003 statute issued by its environmental agency that focuses on radioactive pollution, but does not cover nuclear power safety and operation.[25] There have also been three sets of regulations by the State Council,[26] but these laws and regulations do not present an overarching framework governing the country's nuclear energy sector.

As part of China's post-Fukushima actions, in 2011, the NEA completed the legal research on an atomic energy law.[27] A group of policymakers is reportedly in consultation with various experts in an effort to refine the draft law.[28] The draft reportedly covers—among others— nuclear facilities management, nuclear technology implementation and management, radioactive waste management, nuclear safety, nuclear emergency management, nuclear liability, and export control.[29] It remains unclear, however, when the draft may be submitted to the State Council for review.

Insufficient human capital

Beyond the lack of an atomic energy law, two other major challenges face China's nuclear power governance: the authority and independence of the country's regulators and an insufficient supply of properly trained personnel. Some within the State Council Research Office (a body that makes independent policy recommendations to the State Council) voiced concerns as early as 2010 that nuclear safety governance in China are too fragmented and that its regulatory body, the National Nuclear Safety Administration (NNSA), does not have a sufficient level of independence.[30] China reformed its regulatory organizational structure in 1998, 2003, and 2008, putting the nuclear regulator

---

[25] Zhou, Y., et al., *Is China Ready for its Nuclear Expansion*? *Energy Policy* (2010), doi: 10.1016/j.enpol.2010.10.051, p. 8.

[26] Ibid.

[27] "China's Nuclear Safety Act Drafting is Under Way." *China Nuclear Industry Newspaper,* March 1, 2013. http://news.bjx.com.cn/html/20130301/420329.shtml.

[28] Ibid.

[29] "China atomic law can be submitted for review at the end of the year" (*zhong guo "yuan zi neng fa" cao an you wang nian di zheng qiu yi jian*), *China News,* April 25, 2011, www.chinanews.com/gn/2011/04-25/2994134.shtml

[30] "Maintain Nuclear Perspective, China told," *World Nuclear News,* January 11, 2011.

under the jurisdiction of the Ministry of Environmental Protection (MEP).[31] The NNSA does have authority to report directly to the State Council. However, NNSA is a sub-division within MEP and does not have independent power over personnel matters like selecting safety supervisors or independent budgetary authority.[32] In addition, China's nuclear regulatory and governing apparatus has been described as "dispersed among a multitude of agencies, as many as ten,"[33] including the China Atomic Energy Agency, which plans new capacity and approves feasibility studies for new plants. Finally, NNSA lacks the research and development capacity to set up its own safety technical standards or to verify the safety design of purchased reactor technologies.[34]

Even if organizational structures were properly adjusted, a sound regulatory environment requires adequate supply of capable regulators and inspectors. Insufficient human resources to accommodate the pace and scale of plant expansion has emerged as another serious concern. Senior officials from the NNSA and the NEA have voiced concerns over the inadequate training of professional staff and quality control, saying that China is "short of specialized talent and also short of experience."[35]

Until its expansion in 2011, the NNSA housed only about 60 staff members managing 12 subdivisions and 100 staff members assigned to six regional nuclear safety inspection offices.[36] Additionally, a technical support center that carries out analyses and inspection had about 200 staff members.[37]

After the Fukushima accident, the NNSA staffing was expanded to 85 members, plus 330 across regional offices and 600 at the technical support center (see Table 1). If China is to achieve the 58 GW installed capacity by 2020, however, the NNSA would need to roughly double the current staff size to provide the level of regulatory oversight that is more on par with existing global standards. The global average for the ratio of regulatory staff to a commercial nuclear reactor (average installed capacity of 1 GW) is about 30-40 members. For example, the size of full-time US Nuclear Regulatory Commission (NRC) staff is about 39 members/GW of installed capacity.[38]

---

[31] Integrated Regulatory Review Service Report to the Government of the People's Republic of China, International Atomic Energy Agency, July 2010, p. 8.

[32] Li jingjing, Lin Mingche, Yang Fuqiang, Jason Porter, Reform suggestions for China's nuclear safety supervision system (Zhong guo he an quan jian guan ti zhi gai ge jian yi), April 2012, p. 12.

[33] Bo Kong and David M. Lampton, *How Safely Will China Go Nuclear?* April 6, 2011

[34] Zhou, Y., et al., *Is China Ready for its Nuclear Expansion*? Energy Policy (2010), doi: 10.1016/j.enpol.2010.10.051, p. 20.

[35] Aizhu, Chen, "China's Nuclear Sector Faces Shortages of Specialists," Reuters, September 20, 2010, af.reuters.com/article/energyOilNews/idAFTOE68J04920100920.

[36] Zhou, Y., et al., *Is China Ready for its Nuclear Expansion*? *Energy Policy* (2010), doi: 10.1016/j.enpol.2010.10.051, p. 9.

[37] National Nuclear Safety Administration, *Nuclear Safety Regulatory Framework and Practice in P.R.China*, November 2012, p. 52.

[38] Zhou, Y., et al., *Is China Ready for its Nuclear Expansion*? *Energy Policy* (2010), doi: 10.1016/j.enpol.2010.10.051, p. 9.

Table 1: NNSA staffing shortage remains

Division	Before Expansion	After Expansion
Administration	59	85
Nuclear Safety Centre	170	600
Regional offices	110	331

Source: NNSA, November 2012

Also, nuclear power plants need an adequate supply of capable personnel to safely operate the plants as well as to comply with the regulations. China once had a strong nuclear technology workforce consisting of technocrats, engineers, designers, and researchers, many of whom were spun off from the country's nuclear weapons program.[39] However, the initial modest pace of civilian nuclear development resulted in a dwindling workforce due to lack of interest and academic training opportunities. Today, China has six leading universities, including Tsinghua University, that train nuclear specialists,[40] but student retention has been a major challenge. In 2004, major nuclear engineering programs admitted approximately 370 undergraduates and 145 graduate students, but less than one-third remained in the field after graduation.[41]

Table 2: Survey on nuclear expertise demand in China, 2004-2005[42]

Type of Needed Expertise	**# of Personnel Needed**
Reactor Engineering	2,600
Radiation Chemical Engineering and Radiation Chemistry	2,600
Nuclear Fuel Engineering	1,500
Nuclear Technology Application and Nuclear Science	2,400
Radiation and Environmental Protection	1,300
Nuclear Physics	1,300
Nuclear Geology, Uranium Mining and Metallurgy	1,300
Total (2004-2020)	**13,000**

Source: Guo Yongji, China Atomic Energy Authority (CAEA), 2004 and CAEA, 2009.

---

[39] Zhou, Y., et al., *Is China Ready for its Nuclear Expansion*? Energy Policy (2010), doi: 10.1016/j.enpol.2010.10.051, p. 9.

[40] Aizhu Chen, "China's Nuclear Sector Faces Shortages of Specialists," Reuters, Sept. 20, 2010, http://af.reuters.com/article/energyOilNews/idAFTOE68J04920100920.

[41] Zhou, Y., et al., *Is China Ready for its Nuclear Expansion*? Energy Policy (2010), doi: 10.1016/j.enpol.2010.10.051, p. 9.

[42] Bo Kong, "Civil Nuclear Energy Development in China and U.S.-China Nuclear Cooperation," presentation at Brookings Institution seminar, Washington, D.C., Sept. 17, 2010.

According to an estimate presented by the China Atomic Energy Authority in 2009, China needs 25,000 additional nuclear experts by 2020.[43] In efforts to alleviate the human resource shortage, the nuclear power industry offers competitive wages and excellent benefits. It remains to be seen how quickly Chinese universities can produce personnel with a high level of expertise at the necessary scale to meet demand.

Additional efforts to improve China's civilian nuclear operational capability are reflected in its eagerness to use available international resources. Each civilian nuclear power plant in China generally receives one external safety review a year, either from the IAEA, the World Association of Nuclear Operators, or the China Nuclear Energy Association.[44] For example, between 1983 and 2012, China received 11 missions and eight follow-up visits from the IAEA Operational Safety Review Team (OSART)[45] that included operational and pre-operational safety reviews and technical exchanges that also focused on the reliability of plant operation, factors such as organizational structure and the qualification of personnel.[46]

Antiquated designs

A final and important concern about China's ambitious nuclear expansion is the country's tendency to build older-design reactors. Reactors of older designs like CNP-1000[47] and CPR-1000[48] accounted for roughly half of the units under construction and many on order in China right before the Fukushima accident. While the design itself may not be deficient, the older models do not include many advances that now come with newer generation reactors—the so-called Generation III or III-plus—that are being built today. Gen III and III-plus reactors have design improvements in areas such as fuel technology and thermal efficiency. But the most significant technological improvement is believed to be the incorporation of passive safety features that do not require operator intervention,[49] instead relying on gravity or natural convection to mitigate the impact of abnormal and potentially dangerous events. Also, improvements in Gen III and III-plus reactor

---

[43] Bo Kong, "Civil Nuclear Energy Development in China and U.S.-China Nuclear Cooperation," presentation at Brookings Institution seminar, Washington, D.C., Sept. 17, 2010.

[44] World Nuclear Association, *Nuclear Power in China*, updated March 21, 2013.

[45] IAEA, Operational Safety Review Team (brochure), p. 4 [http://www-ns.iaea.org/downloads/ni/s-reviews/osart/OSART_Brochure.pdf]

[46] Established in 1982, OSART is an IAEA program that assembles and dispatches international teams of experts to conduct in-depth three-week reviews of operational safety performance at individual nuclear power plants at the request of the host country government.

[47] CNP-1000 is a Chinese standard three-loop PWR design the China National Nuclear Corp. had been working with Westinghouse and Framatome (now Areva) since the early 1990s. This design is based originally on the 2-loop Qinshan CNP-300 unit, which is the same design the Chinese are building at Chasma in Pakistan.

[48] The CPR-1000 is a significantly upgraded version of the 900 MWe-class French M310 three-loop technology imported for the Daya Bay nuclear power plant in the 1980s, and is considered a Generation II+ design. It is developed by the China General Nuclear Power Corp. (formerly known as the China Guangdong Nuclear Power Corp.), but its intellectual property rights are retained by AREA.

[49] Stephen M. Goldberg and Robert Rosner, *Nuclear Reactors: Generation to Generation*, American Academy of Arts and Sciences, 2011, p. 6-8.

technology (developed in the 1990s) have aimed at an operational lifecycle of 60 years whereas Gen II reactors (developed in the 1960s) were designed for a typical operational lifecycle of 40 years. If deployed today, the Gen II reactors developed in the 1960s would be about a century behind leading technologies.

New Chinese reactors being built since Fukushima are required to meet safety standards of "third-generation" reactor technology.[50] The much stricter standards for new nuclear construction under the latest nuclear safety plan, particularly the call for eliminating large radiation releases in units built beyond 2016, may accelerate interest in switching its fleet profile away from older designs to next-generation designs that include passive core cooling and other accident-prevention and mitigation features.[51]

Nuclear safety cooperation between the United States and China

A range of cooperation exists between the United States and China that aims to help strengthen nuclear safety in China, including the regulatory environment, human resources, and technology options. Bilateral cooperation has become even more central in the post-Fukushima environment, as the incident highlighted the urgent need for improving nuclear safety standards across the world.

On the regulatory side, bilateral cooperation dates back to 1981, when the US NRC and China's State Science and Technology Commission (and later the NNSA) signed a protocol on Cooperation in Nuclear Safety Matters.[52] Over the following decades, the two sides cooperated on regulatory matters concerning civilian nuclear power plants such as assessment and inspection of construction, operation and decommissioning, emergency preparedness and radiation protection through the exchange of information and specialists, as well as collaborative research and joint seminars.[53]

Personnel training has been a key part of the bilateral cooperative arrangement. For example, the protocol makes numerous areas available to Chinese regulators for training purposes, including accompanying US inspectors on operating reactor and reactor construction inspections, participating in NRC staff training at its center in Tennessee, and inviting US nuclear safety experts to China to facilitate safety related discussions and understandings.[54] Under the auspices of the NRC Assignee Program, which provides foreign regulators with hands-on training for six to twelve months, three Chinese regulators were trained in 2004 on matters such as regulatory requirements for digital instrumentation and control systems and reactor decommissioning process.[55] In 2011-

---

[50] Shi Jiangtao, China's nuclear plan back on track after 19-month freeze, South China Morning Post, October 25, 2012.
[51] Yun Zhou, "China Responds to Fukushima," *Bulletin of the Atomic Scientists*, June 28, 2012.
[52] This protocol was amended and extended in 1986, 1993, and 1998 and renewed in 2004.
[53] *Protocol between the Nuclear Regulatory Commission of the United States of America and the National Nuclear Safety Administration of the People's Republic of China on Cooperation in Nuclear Safety Matters*, signed in 2008.
[54] *Ibid*.
[55] United States Nuclear Regulatory Commission 2001-2009.state.gov/documents/organization/96448.pdf.

2012, the NRC also hosted one Chinese inspector at its Region II for six months for hands-on training.[56]

Westinghouse deal significant for enhancing cooperation

While regulatory best practices and personnel training continue to dominate areas of cooperation today, the nature of cooperation has become significantly more mutually beneficial. This is in large part because of the sale of Westinghouse AP-1000 reactors to China, whose interest in the technology began to heat up in the mid-2000s. Throughout the course of tender, the Chinese side expressed concern that the AP-1000 had not yet received a design certification by the US regulator.[57] But recognizing the value of the AP-1000 reactors to its supply chain indigenization efforts, China eventually decided to become a test case for AP-1000 construction several years before the NRC certified the design at the end of 2011.

The sale of the Westinghouse reactors proved significant for the US regulatory community. China's willingness to assume the role of the "pilot" for US designed advanced reactors opened up a new phase in enhancing bilateral safety engagement. The US regulators have found themselves in a position of learning from the Chinese experiences. For example, during 2011-2012, the NRC sent two resident inspectors for three months and another inspector as a technical reviewer for one month to China to gain lessons learned from ongoing AP-1000 construction at the Sanmen and Haiyan sites.[58]

Moreover, regulators from both countries cooperate through multilateral fora, such as the Multinational Design Evaluation Programme (MDEP). Spearheaded by the Nuclear Energy Agency, this program was established in 2006 to leverage the resources and knowledge of the national regulatory authorities that are or will be tasked with reviewing new reactor designs. Today, the NRC and NNSA staff are frequently engaged in two of three MDEP working groups: the AP-1000 Working Group and the EPR Working Group. Since 2008 the AP-1000 Working Group has been bringing together regulators from the United States, China, the United Kingdom, and Canada (joined in 2009) to facilitate safety reviews of the AP-1000 design, including sharing of design information, application documents, and preliminary findings, as well as identifying significant review issues.[59] In addition, the regulators have shared information on their construction experience and how lessons from the Fukushima accident could be applied and affect their review of the AP-1000 design.[60]

Moreover, Westinghouse has built full-scope plant reference simulators at the Sanmen and Haiyang sites for training prospective AP-1000 operators. So far, 70 operators have

---

[56] *Multinational Design Evaluation Programme Annual Report March 2011 – March 2012*, June 2012, Nuclear Energy Agency, p. 19.

[57] Traditionally regarded as the soundest regulatory body in the world, a design certificate by the U.S. regulators is a highly desired feature of any potential reactor sale.

[58] *Multinational Design Evaluation Programme Annual Report March 2011 – March 2012*, June 2012, Nuclear Energy Agency, p. 19.

[59] Ibid.

[60] Ibid.

been trained at the Sanmen site. After passing license examinations with the NNSA, the trainees will become AP-1000 reactor operators. A similar program is reportedly being carried out at the Haiyang site too.[61] More broadly, the US nuclear industry has been striving for robust consultations with a range of Chinese stakeholders under the auspices of the 2009 US-China Energy Cooperation Program, an industry-level vehicle for bilateral cooperation. The program's Nuclear Power Working Group is set up as a platform for US companies such as Westinghouse, General Electric, and Duke Energy to facilitate the application of advanced US nuclear technologies and industry best practices in China, such as spent fuel upgrades and probabilistic risk assessment.[62]

Operational expertise is also of great importance to the safe expansion of the Chinese nuclear fleet, and at least one US company has recognized a business opportunity in this area. Exelon Nuclear Partners, part of Chicago-based Exelon Corp., has been providing consulting and training services in China since 2011. For example, they have dispatched instructors to Qinshan Nuclear Power Station, a unit of state-owned CNNC, and provided workshops and training classes on the company's organizational principles and designs to about 200 management personnel and plant operators from across the CNNC network.[63] Exelon Nuclear Partners has also agreed with China Power Investments to launch an executive training course that includes onsite training.[64]

Nuclear related educational opportunities have been fostered bilaterally, too. For example, the University of Michigan has been engaged in student exchanges with Chinese institutes since 1998 to teach reactor safety and engineering principles to students from China.[65] This exchange has included educational training in nuclear engineering and the awarding of a master's degree to 13 Chinese students through the CNNC/Westinghouse Fellowship Program.[66]Another specific example of this exchange is a one-month visit to China by University of Michigan students in 2012 that included tours of four nuclear reactor construction sites and the Shanghai Nuclear Engineering Research and Design Institute (a prominent nuclear R&D and design institute in China) as well as exchanges with Chinese nuclear engineering students.[67]

Technology transfer challenges

The effects of the 2007 sale of Westinghouse reactors to China extend beyond regulatory and human resource training, however. After a year-long evaluation by some 200 experts, the Chinese selected AP-1000 reactors for its passive design with simplified safety

---

61 "Westinghouse Installs Simulators," PRWeb, January 10, 2013. www.prweb.com/releases/2013/1/prweb10311445.htm

62 US-China Energy Cooperation Program Progress Report, November 2012, p. 8.

63 Exelon signs nuclear consulting service contract in China, Power Engineering, November 14, 2011.

64 Exelon to further assist nuclear power expansion in China, Power Engineering, September 17, 2012.

65 Stephen V. Mladineo and Charles D. Ferguson, Nonproliferation Policy Education Center Research Memorandum: On the Westinghouse AP 1000 Sale to China and its Possible Military Implications, Mar 29, 2008, p. 6.

66 University of Michigan Department of Nuclear Engineering and Radiological Sciences, *NERS Notes Winter 2011*, p. 11. http://www-ners.engin.umich.edu/about/pubs/archive/ners-notes-2011

67 University of Michigan Department of Nuclear Engineering and Radiological Sciences, *NERS Notes Winter 2012*, p. 15. http://www-ners.engin.umich.edu/about/pubs/ners-notes-winter-2012

system, whose small-modular construction may allow for rapid construction and better cost control as well as a greater degree of localization.[68] Construction of the most advanced pressurized water reactor (PWR) thus began in 2009 at the Sanmen site in Zhejiang province and at the Haiyang site in Shandong province. The Sanmen Unit 1 is slated to be the country's first operational AP-1000 reactor when it comes online in 2014. The sale of Generation III reactors included a technology transfer agreement that has allowed China's State Nuclear Power Technology Corp (SNPTC) to receive over 75,000 technology transfer documents from Westinghouse since 2010.[69] China took a strong step towards modernizing its fleet, while the US and Japan—through the Toshiba acquisition of Westinghouse—gained a significant foothold in China's growing nuclear power sector, where designs had been drawn from Canadian, French, and Russian reactors.

This evolving commercial relationship poses an interesting challenge to US stakeholders. The Chinese nuclear market was too attractive for Westinghouse not to market its most advanced reactors, but the price of engagement was technology transfer that would bolster the technological competitiveness of Chinese vendors. But even if the US/Japan vendor stayed away, however, China would have acquired Gen III reactors from other global suppliers. In fact, alongside Westinghouse, AREVA of France has won a contract to build its advanced reactors in China at the Taishan site. Westinghouse is believed to have decided that more was to be gain by establishing a strong presence in China's nascent yet growing market than risking a permanent shut-out in the face of global competition. Its industrial structure and lower manufacturing cost would likely turn China into a fierce competitor to the US/Japan company when—rather than *if*—the Chinese successfully indigenize Gen III/III-plus technology.

In fact, Westinghouse, SNPTC, and Shanghai Nuclear Engineering Research & Design Institute have been jointly developing an AP-1000-based reactor, which China hopes to begin exporting later in this decade.[70] In May 2013, Westinghouse and SNPTC announced a joint venture to develop a global supply chain for the AP-1000 reactors as well as a plan to develop a small modular reactor that is based on Westinghouse's SMR technology and eventually deploy the SMRs globally. The looming question would then be whether a globally competitive China may see a diminished value to continued nuclear energy cooperation with the United States, especially at the industry-to-industry level.

Yet despite the potential risks, strong rationale for cooperation on the technology front seems to persist. In fact, bilateral nuclear safety technology engagement is growing. In efforts to enhance nuclear power plant safety, the Office of Nuclear Energy and Technology within the US Department of Energy (DoE) engages with China's NEA on a range of nuclear technology issues under the 1988 US-China Peaceful Uses of Nuclear Technologies Agreement. Both countries are currently engaged in activities like probabilistic safety assessment (PSA) workshops and pilot projects.[71] Through the PSA

---

68 *"Nuclear Power in China,"* World Nuclear Association, updated March 21, 2013.
69 Westinghouse Electric gives reactor documents to China, E&E Wire, November 24, 2010.
70 CAP1400 test facility under construction, World Nuclear News, April 4, 2012.
71 Suzhou Nuclear Power Research Institute, *The Fourth Conference on U.S.-China Peaceful Use of Nuclear Technology and Cooperation in Probabilistic Safety Assessment Cooperation as Held Successfully*

workshops, which are under the technical leadership of the Argonne National Laboratory in Chicago,[72] the Chinese engineers aim to acquire better understanding of risk that is informed by decision-making methodologies. In fact, the probabilistic safety assessment is one of the identified areas for improvement, according to the 2011 Chinese Safety Inspection Report. Moreover, DoE is engaged with its Chinese counterparts to promote long-term collaborative R&D activities to further nuclear safety and nonproliferation.

Conclusion

Nuclear energy has become central to energy planning for China, the world's most populous country whose pace and scope of economic growth and social transformation continue to put upward pressures on its national energy demand. Heavy dependence on energy imports and rising levels of greenhouse gas emissions are two of the negative externalities of this immense energy demand. Irrespective of the Fukushima disaster, these two macro factors drive political support for, and public and private investment in, the expansion of nuclear power generation in China.

The gap between China's physical nuclear capacity expansion and institutional capacity, however, warrants serious attention. This concern has fostered a range of cooperative engagements between the United States and China. In one sense, each country's nuclear energy profile is quite different and, therefore, the logic for cooperation may not be readily evident. The United States is home to the largest nuclear reactor fleet in the world but with a declining demand while China is a nascent market with by far the most ambitious build-out targets in the world. Key characteristics of their nuclear energy profiles, however, provide a unique synergy and basis for growing bilateral cooperation.

In fact, as the world continues to learn and process lessons of the Fukushima nuclear accident, the value of nuclear safety cooperation will only grow for the United States and China. The emerging commercial ties between the two countries began shifting the tone of relationship from some variation of "co-existence" to a nascent version of "mutual dependence" in the global nuclear energy sector. As American and Chinese businesses eye an increasing level of partnership in the global marketplace, US participants will have a bigger stake in preventing a low-probability, high-impact event like a nuclear accident in China, even if it did not involve a US-designed reactor.

For bilateral cooperation to effectively enhance nuclear safety standards in the US and in China, the engagement needs to continue growing in a more multifaceted direction. In particular, human dimensions in nuclear safety warrant engagement at regulatory, technology, and commercial levels as each brings a unique and indispensable value that are also synergistic. Bilateral safety cooperation has for the past decades centered on

---

(zhong mei he ping li yong he ji shu he zuo he dian gai lv an quan fen xi di si ci yan tao hui shun li zhao kai), October 29, 2012, http://www.360doc.com/content/12/1105/08/4609583_245795800.shtml

[72] "The Fourth Conference on U.S.-China Peaceful Use of Nuclear Technology and Cooperation in Probabilistic Safety Assessment Cooperation as Held Successfully" *(zhong mei he ping li yong he ji shu he zuo he dian gai lv an quan fen xi di si ci yan tao hui shun li zhao kai)*, Suzhou Nuclear Power Research Institute, October 29, 2012, http://www.360doc.com/content/12/1105/08/4609583_245795800.shtml.

regulatory issues and technology R&D primarily through government-to-government channels. But the introduction of a US-design reactor has opened up an opportunity for closer safety engagement at the industry level too. The US nuclear industry has decades of operational experiences and has a critical role to play in helping to enhance operational safety standards in China, just as US nuclear regulators have been fostering regulatory best practices through bilateral and multilateral engagements despite the limited level of funding and staff. Because operational expertise reside primarily with US utilities (and not government agencies or reactor vendors), greater exchange between US nuclear reactor operators and their Chinese counterparts would help facilitate homegrown efforts to enhance the safety culture in China.

Furthermore, the active reactor build-out involving US-based design illuminates prospects for more mutually beneficial cooperation over safety issues. The construction of AP-1000 has been providing US regulators and engineers—current and aspiring engineers alike—with some first-hand observations and exposures that may otherwise be limited in the United States. Such exposure should be further encouraged, particularly for aspiring US nuclear engineers whose interests in the field and experiences would be an indispensable asset for the United States as long as nuclear energy remains part of its national energy mix.

The continued expansion of its nuclear sector should increase China’s stake in operational safety around the world, forging a strong rationale for China to continue sharing its construction and operational experiences with US stakeholders in decades to come. Bilateral cooperation that is multifaceted and truly mutually beneficial in the area of nuclear safety may lead to a new partnership between the two countries in enhancing regulatory and safety standards around the world.