

Securing China's Weapon-Usable Nuclear Materials

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This article describes the status of China's military and civilian nuclear programs, fissile material production and associated nuclear facilities, and the Chinese nuclear experts and officials' perspectives on the nuclear terrorism threat. It gives details of China's nuclear security practices, attitudes, and regulations, as well as identifying areas of concern. The article recommends ways to strengthen China's nuclear material protection, control, and accounting systems and suggests opportunities for increased international cooperation.

FISSILE MATERIAL STOCKS AND FACILITIES

As a nuclear weapon state with a large and expanding nuclear power sector, China has stockpiles of both military and civilian nuclear material, especially highly enriched uranium (HEU) and plutonium, and the associated production and storage facilities.

There is considerable uncertainty about China's stockpiles of fissile material. It is estimated that China's military inventory of weapon-grade HEU could be about 16 ± 4 tons of HEU and 1.8 ± 0.5 tons of weapon-grade for weapons.¹

China has produced HEU for weapons at two facilities: Lanzhou gaseous diffusion plant (GDP), which began operating in January 1964; and Heping

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GDP, a “Third Line” facility that began operating in 1975. The Lanzhou and Heping GDPs stopped production of HEU in 1979 and 1987, respectively.²

China has produced plutonium for weapons at two nuclear complexes: The first is the Jiuquan Atomic Energy Complex. This site includes China's first plutonium reactor, which began operation in 1966, and the associated reprocessing facilities. The second is the Guangyuan plutonium production complex. The reactor began operation in 1973. Both the Jiuquan and Guangyuan reactors stopped plutonium production in 1984 and 1989 respectively. All these military production facilities have been closed, converted, or are being decommissioned.³

It is estimated that perhaps less than half of China's military stocks of fissile materials could be contained in its nuclear warheads. The rest of the material could be located at a small number of sites including the Jiuquan and Guangyuan plutonium production complexes which conduct HEU and plutonium processing, warhead component production, and weapon assembly; the China Academy of Engineering Physics which conducts research, development and design of nuclear weapons; and at storage facilities of fissile materials (see Table 1). Chinese non-weapon uses of HEU and plutonium are very limited. China's nuclear-power submarines are fueled with low-enriched uranium (LEU).

Military Stock

China has an estimated total inventory of approximately 170 nuclear warheads including about 110 operationally deployed nuclear missiles, and 60 warheads stored for its submarine-launched ballistic missiles (SLBMs), and bombers.⁴

It has been reported that China has a highly centralized storage and handling system for warheads managed by 22 Base under the Second Artillery Corps.⁵ Most of the Chinese warheads are stored at the 22 Base and a very limited number of warheads are in storage at six missile bases. The central warhead storage complex is in Taibai Mountain.⁶ The 22 Base uses advanced physical protection systems including real time video and infrared monitoring, fingerprinting, temperature and humidity controls, and a computerized warhead accounting system.⁷

Civilian Stock

Civil use of HEU in China is limited. China's Experimental Fast Reactor (CEFR), which reached criticality in July 2010, had a first loading of almost 240 kg of HEU (64.4% uranium-235), provided by Russia. The CEFR eventually will use mixed oxide fuel (MOX), as will China's planned future fast reactors. China has a number of HEU-fueled research reactors (see Table 2).

Table 1: China's institutions and nuclear facilities associated with fissile material production.

Nuclear weapon design and manufacture facilities	
China Academy of Engineering Physics (CAEP), Mianyang, Sichuan	Research, development and design of nuclear weapons
Jiuquan Atomic Energy Complex, Yumen, Gansu (Plant 404)	Former plutonium production facility. Conducts HEU and plutonium processing; warhead component production; and weapon assembly.
Guangyuan plutonium production complex, Guangyuan, Sichuan (Plant 821)	Former plutonium production facility. Not clear if conducts plutonium processing, warhead production.
Plutonium production reactors	
Jiuquan reactor at Plant 404	Operated in 1966–1984
Guangyuan reactor at Plant 821	Operated 1973–1989; being decommissioned.
Reprocessing plants	
Jiuquan intermediate reprocessing plant (small) at Plant 404	Operated 1968–early 1970s.
Jiuquan military reprocessing plant (large) at Plant 404	Operated 1970–1984
Guangyuan reprocessing plant at Plant 821	Operated 1976–1991
Pilot reprocessing plant at Plant 404	Civilian; operational since December 2010
Enrichment plants	
Lanzhou Gaseous Diffusion Plant (GDP) (Plant 504), Lanzhou, Gansu	Former military facility; shut down; began operation in 1964 and ended HEU production in 1979.
Heping GDP (Plant 814), Heping, Sichuan	Former military facility; began operation in 1975 and ended HEU production in 1987. Producing LEU for naval reactors?
Lanzhou CEP (Plant 504), Lanzhou, Gansu	Operational since 2001; producing LEU for civilian use.
Hanzhong CEP, Shaanxi	Operational since 1996; producing LEU for civilian use; under IAEA safeguards.

Since 2007, several have been shut down or converted to LEU. Now the major operational facilities include two miniature neutron source reactors (MNSR) (approximately 1 kg of 90% uranium-235 in each), one zero-power fast critical reactor (90% uranium-235, 0.05 kWt), and one PPR pulsed reactor (20% uranium-235, 1 MWt).

China has decided to shut down its MNSRs and build new LEU fueled reactors. In September 2010, China Atomic Energy Authority (CAEA) and the U.S. Department of Energy (DOE) signed an agreement to convert a miniature research reactor in China from HEU to LEU fuel.⁸ The project was implemented

Table 2: China's research reactors.

Reactor	Operator	Characteristics	Status
China Experimental Fast Reactor (CEFR)	China Institute of Atomic Energy (CIAE), Beijing	FBR, 64.4% HEU, 65 MWt/25MWe	Operational since July 2011
Zero Power Fast Critical Reactor	Nuclear Power Institute of China (NPIC), Chengdu, Sichuan	Critical fast, 90% HEU, 0.05 kWt	Operational
PPR Pulsing Reactor	NPIC, Chengdu	Pool, 20% HEU, 1 MWt	Operational
MNSR-SZ	Shenzhen Univ., Guangdong	Tank in pool, LW, 90% HEU, 30 kWt	Operational (to be converted)
MNSR-IAE	CIAE, Beijing	Tank in pool, LW, 90% HEU, 27 kWt	Operational (to be converted under U.S.-China cooperation)
HFETR	NPIC, Chengdu	Tank, LW, LEU, 125 MWt	Converted in 2007, operational
MJTR	NPIC, Chengdu	Pool, LW, LEU, 5 MWt	Converted in 2007, operational
MNSR-SD	Research Institute of Geological Science, Jinan, Shandong	Tank in pool, LW, 90% HEU, 33 kWt	Shut down (reportedly in December 2010)
MNSR-SH	Shanghai Institute. For Measurement and Testing Technology, Shanghai	Tank in pool, LW, 90% HEU, 30 kWt	Shut down in 2007
HFETR Critical Assembly	NPIC, Chengdu	Critical assembly, LW, LEU, 0 KWt	Converted in 2007, reportedly shut down later.
Fast Neutron Critical Assembly	CIAE, Beijing	0 kWt, likely HEU	Operational
HWRR	CIAE, Beijing	LEU, 15 MWt	Operational
SPR	CIAE, Beijing	Pool, LEU, 3.5 MW	Operational
China Advanced Research Reactor (CARR)	CIAE, Beijing	Tank in pool, LW, 19.75% LEU, 60 MWt	First Critical in May 2010
NHR-5	Tsinghua University, Beijing	Heating supply reactor, LEU, 5 MWt	Operational
HTR-10	Tsinghua University, Beijing	High Temperature Gas-Cooled Reactor, coated particle fuels, LEU, 10 MWt	Operational
ESR-901	Tsinghua University, Beijing	Pool, 2-cores, 1 MWt 19.75% LEU	Critical in 1964, operational

Notes. Ministry of Environmental Protection, National Nuclear Safety Administration, Comprehensive Safety Inspection Report on Civilian Nuclear Facilities, 2012, <<http://www.mep.gov.cn/zjyj/201206/W020120615619308262677.pdf>>; NFI, Civilian HEU: China <<http://www.nfi.org/analysis/articles/civilian-heu-china/>>; IAEA Research Reactor, data at <http://nucleus.iaea.org/RRDB/RR/ReactorSearch.aspx>.

in 2013. China is willing to assist other countries in converting their research reactors by utilizing the expertise and experience gained from the relevant cooperation with the United States. China's use of HEU for research reactors in the future would be insignificant.

China produced no civilian plutonium until it operated a pilot reprocessing plant at Jiuquan nuclear complex in 2010. The pilot plant had a production capacity of 50 tHM/year. After operations began on December 21, 2010, in its annual IAEA 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."⁹ In September 2013, China reported that on 31 December 2012 its total civilian stock of separated plutonium was 13.8 kg, indicating that there was no additional plutonium produced between 2010 and 2012, and that the plant operated for only 10 days and below capacity.¹⁰

In recent years, the China National Nuclear Corporation (CNNC) has been negotiating with France's Areva to build a commercial reprocessing plant (800 tHM/year). Recently the CNNC has discussed plans to build a medium-scale commercial reprocessing plant (200 tHM/year) by 2020 and a larger one (800 tHM/year) between 2025 and 2030.¹¹

A pilot MOX fuel fabrication plant (with a capacity of 0.5 MT/year) is now under construction near the pilot reprocessing plant. It will supply the first MOX fuel to China's experimental fast reactor. The plutonium for the MOX fuel will come from the pilot reprocessing plant. Moreover, the CNNC signed an agreement with Russia in 2009 with an intention to purchase two Russian 800 MWe BN-800 fast breeder reactors (FBR). The CNNC also plans to build a series of commercial FBRs by 2032.¹² Significant quantities of separated plutonium will be produced in civilian sector once these reprocessing plants and FBRs are in operation.

In addition, by October 2013, China had 17 operating power reactors with an aggregate installed capacity of about 14 GWe, and an additional 29 reactors under construction, making the Chinese nuclear industry by far the fastest growing in the world. China plans to install a total nuclear capacity of 40 GWe by 2015 and 58 GWe by 2020.¹³ However, all are LEU fueled reactors.

CHINESE ASSESSMENT OF THE RISK OF NUCLEAR TERRORISM

China's government emphasized in its national defense white paper published in 2000 that, "China's nuclear force is under the direct command of the Central Military Commission (CMC)." The document emphasized that China is extremely cautious and responsible in the management of its nuclear weapons, and has established strict rules and regulations and taken effective measures to ensure the safety and security of its nuclear weapons."¹⁴

After the U.S. terrorist attacks on September 11, 2001 (9/11), Chinese experts began to analyze the risks and discuss the management of nuclear and radiological terrorism. In 2003, the China Academy of Engineering launched a risk assessment project involving experts from various national nuclear agencies including National Nuclear Safety Administration (NNSA), China Institute of Atomic Energy, the China National Nuclear Corporation, and the China Academy of Engineering Physics. In 2005 this led to an authoritative report "Management of Nuclear and Radiological Terrorism Incidents."¹⁵

In 2006, the CAEA and the IAEA established a "CAEA-IAEA Joint Training Center on Nuclear Safeguards and Security" with an aim to strengthen the training capability on nuclear safeguards and security. In January 2011, China and the United States signed the "Memorandum of Understanding for Cooperation in Establishing a Center of Excellence on Nuclear Security" (COE). The COE broke ground on 29 October 2013 and should be completed in 2015.¹⁶ The center will serve as a forum for exchanging technical information, sharing best practices, developing training courses, and promoting technical collaborations to enhance nuclear security in China and throughout Asia.

At the 2012 Nuclear Security Summit, Chinese president Hu Jintao emphasized that, "In the future, China will [take further] nuclear security measures, make sure [of] the security of its own nuclear materials and facilities, [and] improve . . . overall nuclear security."¹⁷ Beijing has recently been increasing its concerns about the threats of terrorism.¹⁸ Its recent national defense white paper states, "China still faces multiple and complicated security threats and challenges." The threats are described as the "three forces"—terrorism, separatism and extremism—which are said to be on the rise.¹⁹ Concern also has increased among Chinese experts about the threat of smuggling fissile materials or weapons into China.²⁰ China has borders with Central Asia and Pakistan, where there is a high level of international terrorist activity and there is a cause for higher levels of concern.

Chinese experts, scholars, and officials widely accept four main types of nuclear terrorism: 1) theft, seizure, and the explosion of nuclear weapons; 2) theft, smuggling, purchase, and other means of acquiring nuclear materials, and manufacturing and explosion of a nuclear device; 3) sabotage of nuclear facilities; and 4) radiological dispersal device or "dirty bomb."²¹ But many Chinese nuclear experts do not see the terrorism threat as realistic or urgent. They argue it would be extremely difficult for terrorists to acquire the required fissile materials or a nuclear weapon within China due to China's strict security system for its very limited weapon-usable nuclear materials and nuclear arsenal.

Many Chinese experts believe it is implausible (if not impossible) for Chinese nuclear weapons to be stolen because China's arsenal is relatively small, tightly monitored, and guarded by heavily armed forces.²² Moreover, most Chinese warheads are stored deep underground in remote mountains and the locations are kept highly secret and would be very difficult for outsiders to access.

Chinese nuclear weapon experts believe that terrorists do not have the capabilities to produce highly enriched uranium and separated plutonium. However, once they acquire enough fissile materials through theft, smuggling, purchase, and other means, they would be able to manufacture and detonate a crude nuclear weapon. In particular, with enough HEU, a gun-type bomb is well within the capabilities of a sophisticated terrorist group. While Chinese experts see HEU as the preferred material for terrorists, they agree that any grade of plutonium, including reactor-grade, could be used to build an implosion bomb.²³

Chinese nuclear experts believe that the probability of terrorists getting access to fissile materials inside China and manufacturing a crude bomb is very low. They argue that the technologies necessary for manufacturing, delivering, and detonating a weapon are very difficult for Chinese terrorists to obtain. However, experts are not able to rule out the possibility of terrorists smuggling a nuclear weapon or nuclear materials from outside of China.²⁴

As the number of China's nuclear power plants is rapidly increasing, the risk of sabotage of civilian nuclear facilities, particularly a nuclear power plant, is seen as becoming more plausible.²⁵ Also, the Fukushima accident may increase the interest of terrorists in targeting power reactors in China. But experts perceive the risk of a major radioactive release resulting from a terrorist sabotage of a nuclear power plant as very low because the terrorists lack the means or tools to conduct such attacks and China's current security system should be good enough to prevent them.²⁶

Instead, Chinese experts believe the most realistic threat of nuclear terrorism in China is from a radiological dispersal device or "dirty bomb."²⁷ One reason for this concern is that China has many radioactive sources distributed widely, and also many orphan and spare sources. Moreover, there is a weaker control and management system for these distributed sources.²⁸ Based on a survey in 2002 by the State Bureau of Environmental Protection, the Ministry of Public Health, and the Ministry of Public Security, China had a total of 63,721 radioactive sources and 8,312 users, including hospitals, industry, agriculture, research, and education departments. In addition, approximately 13,000 spent radioactive sources were awaiting disposal.²⁹ As one nuclear expert estimated, approximately 2,000 radioactive sources were completely uncontrolled due to problems in the management system.³⁰ While the government makes efforts to find orphan sources, about 1000 radioactive sources are believed to be lost.³¹

Some experts view China's commitments to upgrading nuclear security as more an international requirement than as a response to a serious threat. Some argue that nuclear terrorism may be a problem to the United States, but it may be not so urgent for China.³² China is also facing the challenge of complacency that exists among a significant number of senior nuclear experts and nuclear industries. They believe that China already has strict nuclear

security systems that have worked well and “free of accident” over past 50 years. One nuclear expert from CNNC has pointed out that when it comes to nuclear materials the record shows “no[t] one gram missed and no[t] one item disappeared” over the last 50 years.³³

In addition, some argue that the stricter the security standards employed, the higher the capital and operating costs. In particular, for bulk-processing facilities (e.g., fuel fabrication plants, reprocessing facilities, and enrichment plants) limited financial resources have often caused operators to give safety and security a low priority when allocating resources. Moreover, security is given even a lower priority than safety. In some cases, the guards turn off the detectors at the portal of enrichment facilities to avoid wear and early replacement.³⁴ Also, some doubt whether it is worth the money and time to have a stricter security system.

The rapid growth of the nuclear industry has created a serious shortage of adequately trained security personnel and other necessary staff. As more employees are hired from non-nuclear fields, the safety and security culture is further diluted. As plants have converted from military to civilian missions, a culture of secrecy still exists and operators are not willing to share information about problems with outsiders, including inspectors.³⁵

To overcome these challenges, the operators must believe that a terrorist threat is real. The possibility of insider theft of nuclear materials cannot be ruled out, particularly as China increasingly develops into a market-oriented society with an associated increase in corruption. Indeed, some Chinese experts worried that the big changes in China's society over recent decades could increase criminal activity thus increasing the likelihood for attempted thefts and smuggling.³⁶ Many experts believe that the more pervasive corruption becomes, the higher is the potential for the theft of materials and the need for increased security.³⁷

The risk of an insider threat is perhaps the most challenging because the insiders have authorized access to nuclear material areas and understand the operations, rules, policies, and regulations concerning nuclear materials.³⁸ Some insiders are highly trained in handling nuclear materials and have the opportunity to understand how to defeat safety and security systems. One or more of these individuals could work with other on-site personnel or outsiders and take advantage of access to perform acts of theft or sabotage and potentially aid terrorists.

HEU and separated plutonium in China's civilian sector could be more vulnerable to insiders. In particular, some Chinese nuclear experts are aware of the threat of fresh HEU or spent HEU fuel at research reactors.³⁹ These reactors are located at institutes that are not as well controlled and guarded as the military sites because of a shortage of funding. Moreover, the security and control system at some old facilities is of a lower level than that of new ones.

Separated plutonium at China's civilian pilot reprocessing plant poses another challenge. The pilot plant began construction in 1995 and was not based on security-by-design. It shares some facilities with the previous military reprocessing plant which were not designed using a modern material control and accountability (MC&A) system. Consequently, the accounting system might not be adequate for the new mission. Indeed, one problem with the plant is that the values for the material unaccounted for (MUF) are higher than is considered acceptable.⁴⁰ Chinese nuclear experts are concerned that, the plutonium products could be a target for nuclear terrorists.

CHINA'S NUCLEAR SECURITY: PROGRESS AND CHALLENGES

Legal Framework

Since the mid-1980s, China has issued a number of regulations, rules, and technical guidelines regarding the security of nuclear and radioactive materials and nuclear facilities. In China, there are several categories of laws and regulations: Statutory law requiring approval by the National People's Congress, State Council law and regulations, departmental rules, and regulator's guidance or documents.⁴¹ China does not yet have a statutory law for nuclear development, safety and security; it is still drafting the Atomic Energy Law.

China has joined nearly all the international legal instruments relevant to nuclear security, including the 2005 amendment of the 1980 Convention on the Physical Protection of Nuclear Material and the International Convention for the Suppression of Acts of Nuclear Terrorism. It is also bound by United Nations Security Council Resolution 1540. Fulfilling those international obligations is a major driver of the development of China's nuclear security. China has improved and built up its legal system in some areas related to nuclear security, including nuclear export control, control of radioactive materials and their shipments, and nuclear emergency response.⁴² However, regulations and rules on the security of nuclear materials and facilities have not been kept up to date.

Currently, the only major legal instrument on fissile material control is the Regulations for Control of Nuclear Materials, issued in 1987.⁴³ Based on this regulation, China issued in 1990 the "Rules" for Implementation of the Regulations on Nuclear Materials Control.⁴⁴ This is also the only rule governing nuclear material control.

When both the 1987 Regulation and 1990 Rules were issued, all of China's weapon-usable fissile materials were produced by its military production facilities and were used almost solely for weapons purposes (a very small portion for HEU-fuel reactors), so the 1987 Regulation and 1990 Rules may still be applied to China's military nuclear materials and nuclear facilities.

In 2008, the NNSA issued the Nuclear Facility Physical Protection Guidelines that updated the guidelines for physical protection measures for all civilian nuclear facilities.⁴⁵ However, it is not clear whether the measures for the military nuclear facilities were updated.

The CAEA is responsible for the security of China's nuclear materials and for adopting a licensing system. To become licensed, an operator must establish an effective nuclear material protection, control, and accounting (MPC&A) system that meets the regulatory guidelines. Inspection activities include verifying the integrity of accounting records, physical inventory changes, measurement and quality control systems, material balance, and effectiveness and reliability of physical protection measures. If a facility is found in violation of these regulations, it could be punished by warning, penalty, or revoking its license, depending on the seriousness of the violation.

It should be noted that these regulations and rules on security of nuclear materials and facilities were issued before the 9/11 attacks, and do not mention the threat of nuclear terrorism. These regulations should be updated to reflect the potential threats posed after the 9/11 attacks.

Physical Protection System

China's management of nuclear material security and physical protection is mainly based on the 1990 Rules and the IAEA related recommendations (INFCIRC/225 Rev.4). All facility operators are required to establish a facility level organization in charge of the security of facilities and nuclear materials. Similar to the IAEA recommendations on physical protection of nuclear materials, China divides its protection requirements for nuclear material into three categories based on type, quantity, and harmfulness of the nuclear material (see Tables 3 and 4).⁴⁶

The most updated and detailed documents on physical protection of China's nuclear facilities can be read from the 2008 NNSA guidelines of "Nuclear Facility Physical Protection." Before the 9/11 attacks, China's nuclear facilities were mainly designed to protect from natural disasters or accidents. However, since the 9/11 attacks, China has made substantial changes in its nuclear security approaches, such as protecting nuclear facilities against design basis threat (DBT), including both outsider and insider adversaries. The 2008 guidelines also require specific physical protection measures for three categories of nuclear facilities in China (see Tables 5 and 6). The protection measures are ranked according to the relative attractiveness of the stored material, the nature of nuclear materials and facilities, and potential consequences of theft. All Chinese civilian nuclear facilities should meet the 2008 Guidelines requirements. Many old facilities have been upgrading their security systems.

Table 3: Categorization of fissile materials in China.

Category I	<ul style="list-style-type: none"> • 2 kg or more unirradiated plutonium • 5 kg or more HEU
Category II	<ul style="list-style-type: none"> • Less than 2 kg but more than 10 g unirradiated plutonium • Less than 5 kg but more than 1 kg HEU • 20 kg or more unirradiated uranium-235 (10% but less than 20% enriched) • 300 kg or more unirradiated uranium-235 (enriched to less than 10%; not including natural and depleted uranium)
Category III	<ul style="list-style-type: none"> • 10 g or less unirradiated plutonium; • 1 kg or less but more than 10 g HEU • 1 kg or more but less than 20 kg unirradiated uranium-235 (10% but less than 20% enriched) • 10 kg or more but less than 300 kg unirradiated uranium-235 (enriched to less than 10%; not including natural and depleted uranium)

Note. Rules for Implementation of the Regulations on Nuclear Materials Control of the People's Republic of China, National Nuclear Safety Administration (NNSA), the Ministry of Energy, and the Commission of Science, Technology, and Industry for National Defense, September 25, 1990. Chinese version is available at CAEA website <[www: http://www.caea.gov.cn/n16/n1130/77224.html](http://www.caea.gov.cn/n16/n1130/77224.html)>. Note that the 1990 Rules do not cover other materials, such as U-233.

Table 4: Physical protection measures for fissile materials at fixed sites.

Category I	<ul style="list-style-type: none"> • At least two complete, reliable physical barriers; vault or special security container for storage • A technical protection system with alarm and monitoring installations • 24-hour armed guard • Special pass for all people entering the site • Strict registration control and required escort for all off-site personnel • Vault access controlled by "double men and double lock" system
Category II	<ul style="list-style-type: none"> • Two physical barriers with one that is complete and reliable; a "strong room" or "solid container" type storage area • Alarms or surveillance protection equipment provided in vital areas • 24-hour armed guards or specially assigned persons • Special pass for all people entering the site
Category III	<ul style="list-style-type: none"> • One complete and reliable physical barrier • Specially assigned persons for watching or letting nuclear material be placed in security containers

Note. Rules for Implementation of the Regulations on Nuclear Materials Control of the People's Republic of China, the National Nuclear Safety Administration (NNSA), the Ministry of Energy, and the Commission of Science, Technology, and Industry for National Defense, September 25, 1990. Chinese version is available at CAEA website <[www: http://www.caea.gov.cn/n16/n1130/77224.html](http://www.caea.gov.cn/n16/n1130/77224.html)>.

Table 5: Three categories of civilian nuclear facilities in China.

Category I	Category II	Category III
Facilities containing category I nuclear materials	Facilities containing category II nuclear materials	Facilities containing category III nuclear materials
100 MW(th) reactors or larger	2–100 MW(th) reactors	Less than 2 MW(th) reactors
Spent fuel pools with some new discharged fuels and the total radioactivity greater than 10^{17} Bq cesium-137	Middle-level liquid and high-level solid nuclear waste storage and processing facilities	Low-level liquid and middle-level solid nuclear waste storage and processing facilities
Spent fuel reprocessing facilities	Spent fuel pools requiring active cooling systems and not covered by category I case	Facilities where direct exposure dose rate without shielding measures is larger than 100 mGy/h at 1 meter distance
High-level liquid nuclear waste storage and processing facilities	Facilities where any on-site criticality accidents without control measures can pose impacts beyond 0.5 km from the facility perimeter	Facilities where any on-site criticality accidents without control measures can pose impacts within 0.5 km from the facility perimeter
Others facilities	Others facilities	Others facilities

Notes: Ministry of Environmental Protection, National Nuclear Safety Administration, "Nuclear Facility Physical Protection Guidelines," 2008, HDA501/502. Note that guidelines do not contain an exhaustive list, so they could apply to facilities that are not explicitly included in the list.

However, the 2008 Guidelines lack clearly defined standards for each nuclear facility. Facility operators typically design their own DBTs on a case-by-case basis according to a number of factors, including the socioeconomic situation in the surrounding area.⁴⁷ China's current DBT for nuclear facilities may not include extreme adversary scenarios, such as a 9/11-type attack.⁴⁸ As the director of the NNSA, Li Ganjie, has noted, under the existing DBT, civilian facilities might be insufficient to repel attacks from larger and better-organized terrorist groups, or attacks involving powerful weapons.⁴⁹ Some experts argue that China has been unable to construct a more systematic and rigorous approach to DBTs mainly because it lacks familiarity with the necessary concepts and processes.⁵⁰

China applies modern concepts of Physical Protection System (PPS) to its nuclear facilities, e.g., modern technology and techniques for the *detection* function of its PPS, including microwave detectors, active infrared sensors, and video motion detectors and a number of technical measures to the *delay* function at nuclear facilities, including double fences with intrusion detectors and

Table 6: Physical protection measures for civilian nuclear facilities in China.

Category I	Category II	Category III
24-hour armed guard at access points in the vital, controlled and protected areas.	24 hour armed guard at access points in controlled and protected areas.	Facilities located in controlled area
Alarm and monitoring system at all entrances and access areas	Alarm and monitoring system at all entrances and access areas	Communication and monitoring system at all entrances and access areas
Required pass or badge for authorized personnel and vehicles	Required pass or badge for authorized personnel and vehicles	Required pass or badge for authorized personnel and vehicles
Strict registration control and required escort for all off-site personnel and vehicles	Strict registration control and required escort for all off-site personnel and vehicles	Emergency power backup system An office with security personnel on duty
A "two man and double-lock" rule for the vital area	Radioactive material detection systems installed at access to the protected area	
Radioactive material detection systems installed at access to the protected and vital areas	Emergency power backup system Centralized control to manage physical protection system	
Emergency power backup system		
Centralized control to manage physical protection system		

Note. Ministry of Environmental Protection, National Nuclear Safety Administration (NNSA), "Nuclear Facility Physical Protection Guidelines," 2008, HDA501/502. Note that guidelines do not contain an exhaustive list, so the guidelines could apply to facilities that are not explicitly included in the list.

clear zones between them, and reinforced concrete barriers.⁵¹ There are, for example, detection systems for radioactive material and prohibited items installed at access points to the protected and vital areas at nuclear facilities. To control access to facilities, the plants use mobile barrier gates, metal detecting gates, electric retractable gates, floor-to-ceiling turnstile doors with barcode reading systems, biometric identification systems, and alarm and video monitoring systems at all access points.⁵²

The operators for Category I nuclear facilities are required to have hardened central alarm stations, armed forces on duty 24 hours a day, and a "two man and double-lock" rule for the vital area. Also, the licensee is required to set

up a group and prepare detailed contingency plans to prevent nuclear terrorist acts and nuclear accidents.⁵³ Furthermore, the operator of a nuclear facility is required to improve and update its physical protection system and to maintain the system's effectiveness.

Before 1998 the concept of vulnerability analysis of physical protection did not receive attention and there was no evaluation and theoretical analysis about physical protection systems.⁵⁴ Now Chinese facilities are required to conduct in-depth vulnerability assessments with identified vulnerabilities corrected in a timely manner.⁵⁵ Also the operator is required to use technical approaches to strengthen the reliability of the security system, including performance tests of detection and assessment and the use of reliable and compensatory techniques.⁵⁶ China does not, however, conduct realistic "force-on-force" exercises to test the performance of its nuclear security systems.⁵⁷

Material Control and Accountability System

Based on the 1990 Rules and related IAEA standards, China has established and revised its nuclear materials control and accounting system. In 2008, the NNSA issued new guidelines for "the standard format and content of nuclear facilities safety analysis report on MC&A."⁵⁸ The MC&A system must include clear assignments of material balance areas and key measurement points, control of measurement quality, physical inventory of materials, material unaccounted for (MUF) assessment, and recording and reporting system. The licensee must establish nuclear material physical inventory procedures with requirements including conducting complete and strict physical inventories at least once a year and conducting physical inventory for such material as plutonium-239, uranium-233 and HEU at least twice a year. The licensee is required to ensure the record of nuclear material accounting is clear, accurate, systematic, and complete, and maintained at least for five years. If the MUF is more than twice the standard deviation of MUF, then an investigation of the loss would be initiated.

The big challenge for China to have an effective MC&A system is its reprocessing facilities. In fact, the operation of its pilot reprocessing plant discloses some problems. For example, the amount of wastes produced and the MUF were both very high.⁵⁹ The larger reprocessing facilities that China plans to build with capacities of 200 tHM/year and 800 tHM/year, would be more challenging to effective MC&A than the small pilot facility. Thus, to establish those reprocessing facilities would increase the risk of theft and increase the security burden for operators.

Unlike nuclear power plants, which have income from market sales of electricity, fuel cycle facilities including the pilot reprocessing plant are currently heavily dependent on government financial support. Those facilities often lack

enough money to hire better-qualified people and install more and better sensors and equipment for effective MC&A system.⁶⁰ Given the fact that the risk of insider theft at these bulk processing facilities is higher, these facilities should be required to have effective security systems to control and account for all their materials.

STRENGTHENING CHINA'S NUCLEAR SECURITY

China could take steps to install a more reliable and effective security system to ensure that all its nuclear weapons, weapon-usable nuclear materials, nuclear facilities, and transporters are secure against threats it is likely to face. The following measures would improve China's existing nuclear security system.

Improving Physical Protection System

China needs to review, update, and upgrade its requirements, including the DBT, for designing physical protection for the nuclear facilities at military and civilian sectors. The operator must be required to develop and implement security plans that provide effective protection against a DBT that includes the full spectrum of plausible adversaries and tactics, including not just brute force but also deception, and stealth from both insiders and outsiders.

China should update its 1987 Regulations and 1990 Rules regarding nuclear materials control, and issue new strict and clear regulations and rules based on a minimum DBT standard. To ensure the new regulations and rules are effectively implemented for facilities and transporters with nuclear weapons and weapon-usable fissile materials, China would need an effective system of enforcement and a constantly developing and improving nuclear security system that would not stagnate. Just as with nuclear safety, the focus should be on continuous improvement, constantly working to find and fix remaining vulnerabilities and find more effective approaches.

As the newly issued INFCIRC/225/Revision 5 recommends, China should use realistic "force-on-force" exercises to test the performance of its nuclear security systems' ability to detect and defeat intelligent adversaries using asymmetric attacks. The newly established CAEA National Nuclear Security Technology Center, responsible for the construction, management, and operation of China's Center of Excellence on Nuclear Security, is considering conducting such tests at its training site.⁶¹ However, realistic tests must be carried out at operating facilities and Chinese security experts may lack the experience and capabilities to carry out such tests at actual sites without affecting the safety and security of the nuclear facilities during the tests.⁶² China could learn the practice of "force-on-force" exercises through CAEA and U.S. DOE cooperation.

For example, Chinese experts could be invited to witness such exercises at U.S. sites as have other countries, including France and Japan.

Improving MC&A and Reducing Internal Risks

In order to prevent acquisition of nuclear materials, China needs to improve its MC&A approach at its bulk processing facilities (e.g., fuel fabrication, reprocessing, and processing of aging fissile materials for weapons). Those facilities are facing major challenges in their shortage of modern equipment, technologies, and related professional personnel rooted in the mainly inadequate financing (unlike nuclear power plants that earn higher profits, fuel cycle facilities are dependent mainly on government support). Nuclear security experts have emphasized that it is far easier for insiders to steal small amounts at a time without anyone noticing at those bulk processing facilities. Nearly all of the seizures of stolen HEU and separated plutonium that have occurred have been of bulk material such as powders, apparently stolen without detection by insiders at bulk processing facilities.⁶³ Thus, it is essential for China to take effective MC&A measures to reduce the chances of insider theft.

The government should make sure these facilities have adequate finance to have modern equipment and technologies and related professional personnel. For instance, each facility doing bulk processing of weapons-usable materials should use reliable and accurate measurement methods and equipment for material accounting. The operator must establish an accounting system that will rapidly detect if a significant quantity is removed, be able to locate the removal in time and space, and identify who had access.

The operator, in cooperation with relevant government departments, must have an effective program for personnel reliability screening to strengthen access control.⁶⁴ For example, all personnel with access to vital areas must be subject to drug testing, background checks, physical examination, and psychological or mental fitness tests; these tests should be repeated at specified regular intervals. The license conditions for facility operators should specify that personnel must report suspicious behavior to an official authority; the regulations should require constant surveillance of inner areas when they are occupied using either a two-person surveillance system or a technological surveillance system including devices such as closed circuit television cameras.

International Assurance through Transparency and Cooperation

China should consider becoming more transparent in order to build confidence in the international community that a robust nuclear security program is in place. Some experts suggest that a nation can make substantial amounts

of information about its nuclear security conditions public without compromising sensitive information.⁶⁵

China could release details of its nuclear security regulations, as well as general reports on implementation of and compliance with those regulations; share information with others confidentially or publicly about approaches, procedures, regulations, best practices, and lessons learned.

China should allow experts organized by the IAEA to conduct reviews of the country's nuclear security arrangements. These reviews have been found by many other states to be helpful in identifying options to improve nuclear security. China is considering whether to have the International Physical Protection Advisory Service (IPPAS) mission to China. It would be advisable for China to have such a mission soon. The IPPAS missions would review and compare China's physical protection measures with international guidelines and best practices and make recommendations for improvements. Also China should consider inviting other IAEA missions including International Nuclear Security Advisory Service (INSServ) mission and State System for Accountability and Control (SSAC) Advisory Service.

China could encourage its relevant nuclear security professionals to participate in WINS and other workshops and training that facilitate the identification and sharing of best practices.

China could also host some reviews of its nuclear security arrangements by another country under a bilateral-like agreement or program, such as, expanding China and U.S. cooperation to include security reviews of some facilities beginning with civilian facilities including HEU-fueled reactors and the pilot reprocessing plant while the United States does the same for China.

Further, China and U.S. cooperation should expand to the defense sector that deals with nuclear weapons and most sensitive nuclear materials. Primarily, the two governments should restart the U.S.-China lab-to-lab program that ran from 1995 to 1998 partly to help create an interest in modern security systems in China by demonstrating the advantages of a material protection, control, and accounting system.⁶⁶

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