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Congressional Testimony

China's Nuclear Forces

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The United States government in recent years has paid greater attention to the status of military-civil fusion (MCF) in China's economic and technological development and its potential implications for U.S. trade and cooperation with China. In a hearing conducted by the U.S.-China Economic and Security Review Commission on June 7, 2019, participants documented and discussed this concern regarding a number of specific industry and technology areas.[1] Today I will consider some aspects of China's peaceful use of nuclear energy, including China's cooperation with U.S. government and industry in this field, in the light of the Commission's concern about MCF.

Military-civil integration, according to Chinese state media, was "upgraded to a national strategy in March, 2014."[2] Nuclear cooperation between the United States and China began more than twenty years before this date, and it has continued to the present; MCF, depending on how it is conceptualized or defined by U.S. government agencies,[3] may therefore be pertinent to the appropriation or diversion of nuclear technology, equipment, and materials, developed or acquired for the peaceful use of nuclear energy, to make nuclear weapons, and especially, nuclear weapons materials.

Nuclear technologies and materials are relevant to considerations of MCF because they are inherently dual-use: They can be employed for making nuclear weapons and/or for generating electricity. Furthermore, some nuclear-related technologies may be useful to other military uses, such as naval nuclear propulsion.

In light of the dual-use nature of nuclear technology and materials, since the end of World War II the United States led the way in the creation of a multilateral governance framework to control the spread of sensitive nuclear items from nuclear-armed states to states that do not have nuclear weapons. Most countries that developed nuclear energy and nuclear weapons joined the U.S. in this effort. China supported these efforts beginning in the mid-1980s, when it joined the International Atomic Energy Agency (IAEA), the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), the NPT's Zangger Committee for nuclear export controls, and the Nuclear Suppliers Group (NSG), a global export control association of the world's leading vendor countries for nuclear technology, materials, and equipment. It was not a coincidence that China joined these critical multilateral organizations and mechanisms after the Chinese central government decided to establish a nuclear power industry in China.

Both China and the U.S. are recognized by the NPT as nuclear weapon-possessor states. While Article I of the NPT prohibits a nuclear-armed state from transferring nuclear weapons to any recipient, in practice the international trade elements of the global nonproliferation governance system, including both the NPT and the NSG, are primarily concerned with the threat of

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[1] https://www.uscc.gov/hearings/technology-trade-and-military-civil-fusion-chinas-pursuit-artificial-intelligence-new

[2] http://eng.chinamil.com.cn/view/2017-01/23/content_7462990.htm

[3] https://cset.georgetown.edu/wp-content/uploads/CSET-Assessing-the-Scope-of-U.S.-Visa-Restrictions-on-Chinese-Students.pdf p. 23

uncontrolled spread of sensitive nuclear technologies, materials, and equipment to states that are not already nuclear-armed.

Nuclear commerce between China and the U.S. is governed by a bilateral Agreement Between the United States and the People's Republic of China Concerning Peaceful Uses of Nuclear Energy. This agreement has a 30-year term and was renewed by the U.S. government on 29 October 2015. The agreement has been amended twice: once during the period 1985-1998, and again prior to its renewal in 2015, in part to address specific concerns by Congress and the Executive Branch about China's potential use of U.S.-origin technologies in its nuclear weapons program.[4]

A Dual-Use Industry

China has pursued mastery of nuclear technology for civilian and military purposes for seventy years. Over this period, peaceful-use and defense interests coexisted in critical Chinese nuclear energy organizations, all of which were ultimately controlled by the Chinese central government and the Chinese Communist Party (CCP). In some cases, control may have been indirect through government personnel who were party members. Whereas the People's Liberation Army (PLA) reported directly to the CCP, China's nuclear laboratories reported to government ministers.

Chinese scientists in R&D and academic organizations were initially interested in the peaceful uses of nuclear energy; after the Chinese Politburo decided in 1955 to produce nuclear weapons, many scientists were put to work on China's nuclear weapons program. After China successfully tested a nuclear weapon in 1964, the Cultural Revolution interrupted nuclear power development; China began building nuclear power plants only during the 1980s, following decisions by the state and CCP to launch a massive modernization drive for China.

As in the other NPT nuclear weapon states after World War II, including the U.S., in China development of nuclear technology for electric power and other peaceful uses relied upon the cadres of scientists and engineers that had established the foundations of China's nuclear defense program. Maoist China was a rigidly, centrally controlled state; from the outset, only organizations controlled by the Chinese state were involved in nuclear power development and deployment. This is still the case today. Beginning in the 1970s Chinese leaders advocated nuclear power to overcome increasingly crippling energy shortages, and nuclear scientists articulated an R&D vision to strengthen China's energy independence and use uranium and plutonium to generate nuclear power for hundreds of years. Since the 1980s China has promulgated official "strategic plans" for nuclear power development that suggest that, next to defense, the provision of nuclear power is a quasi-strategic activity. Secondarily, the government's resolve to assign organizations and cadres responsible for nuclear weapons production the role of developing nuclear power was consistent with its desire during the 1980s under "modernization" to allocate

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[4] An excellent account of the history and contents of the agreement was published by the Congressional Research Service in 2015: https://fas.org/sgp/crs/row/RL33192.pdf

resources, on margin, away from China's defense sector and into industrial applications that would aid national development and generate national wealth.

The dual-use nature of nuclear science was reflected in the shared peaceful-use and nuclear defense functions of organizations responsible for China's production of nuclear fuel materials; these materials were associated with nuclear reactors (both for production of weapons plutonium and for power generation) and with uranium enrichment plants (both for production of reactor fuel and for nuclear weapons material). As was the case in all other NPT nuclear weapon states, scientists and engineers trained in Chinese universities and academies have found employment in nuclear defense-related establishments and/or organizations and companies focused upon peaceful uses of the technology. The science behind nuclear peaceful uses and nuclear defense applications is identical; as in other states, personnel may cross over between peaceful and non-peaceful employment.

Since the genesis of China's nuclear program, the most important nuclear industry organization in China, responsible for peaceful applications and also for producing nuclear materials for non-peaceful uses, has been the China National Nuclear Corporation (CNNC), one of two large state-owned enterprises (SOE) that dominate the Chinese nuclear power landscape. CNNC, its subsidiaries, and affiliated companies have long been responsible for the processing and production of nuclear fuel for both peaceful and military applications in China. They are also deeply engaged in technology R&D, waste management, nuclear power engineering, and nuclear power plant construction. In 2020 the U.S. Department of Defense included CNNC on a list of 20 Chinese companies linked to the Chinese military, as required by the 1999 National Defense Authorization Act.[5] A second large nuclear SOE, China General Nuclear (CGN), was established during the 1990s by the Chinese state to function separately from CNNC, initially to partner with foreign, especially French, industry in the development, construction and operation of modern nuclear power plants. Over the last three decades, CGN has grown in size and stature, and it has objected to CNNC's tight grip over activities in the nuclear fuel cycle.[6] In 2018, NNSA and the U.S. Department of Energy issued a "presumption of denial" for nuclear export license applications to CGN, its subsidiaries, and related entities.[7] In 2019, the U.S. Department of Commerce included CGN on its Bureau of International Security Entity List.[8]

Some institutions also have specific dual-use histories. A CNNC affiliate, the China Institute of Atomic Energy (CIAE), has long played a leading role in the development of new and advanced nuclear fuels. Beginning in the 1950s, its scientists "concentrated largely on basic research and the

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[5] https://www.axios.com/defense-department-chinese-military-linked-companies-856b9315-48d2-4aec-b932-97b8f29a4d40.html

[6] Mark Hibbs, *The Future of Nuclear Power in China*, Washington, D.C.: Carnegie Endowment for International Peace, 2018, p. 75.

[7] https://www.energy.gov/sites/prod/files/2018/10/f56/US_Policy_Framework_on_Civil_Nuclear_Cooperation_with_China.pdf

[8] https://asia.nikkei.com/Economy/Trade-war/US-adds-China-s-biggest-nuclear-company-to-entity-list

development of peaceful uses of atomic energy" including research reactor projects. However, "at some point before July 1960 the Defense Science and Technology Commission [a central government agency] turned to the Institute of Atomic Energy to initiate research and development" on production of uranium hexafluoride (UF6), which was needed for China's nuclear weapons program.[9] When China launched its nuclear power program in the 1980s, CIAE was again assigned a key strategic role, for R&D activities for the development of future fast reactors, including for the plutonium fuels that would eventually be needed for these reactors.

China continues to confine participation in nuclear energy activities to selected organizations, led by CNNC and CGN and their related entities. In recent years, the Chinese state has allowed more firms to invest in the ownership of new nuclear power plant projects, in particular cash-rich utility companies from the country's non-nuclear electric power sector; they might not have a key role in strategic decision making about technology development, procurement, or deployment. For companies involved in strategic industrial production including nuclear power, the CCP is involved in all top-level personnel decisions. Senior SOE managers are promoted into central and provincial governments where they retain influential links to the companies. SOEs have a CCP hierarchy parallel to the management hierarchy in which the party secretary may have more authority than senior managers. That said, since the 1990s, the corporatization of China's electricity industry sector has to a certain extent challenged the authority of the CCP at the business management level.[10]

Foreign Cooperation

During two distinct phases beginning in the 1980s, China relied upon cooperation with foreign countries to develop nuclear power. For most of this time, it would appear that conventional expectations in the U.S. and other Western governments and industry were that China's political relations with these countries would over time normalize and intensify in step with China's economic globalization. Concerns about the potential for foreign-supplied technologies aiding China's nuclear weapons program were presumably dampened by the relative stasis in China's nuclear weapons enterprise. During the 1980s and 1990s, China implemented "boutique" projects to build modern, commercial-scale nuclear power plants, in partnership with experienced foreign companies from Canada, France, and Russia. The foreign firms, backed by their governments, helped China build and operate the power plants. These foreign firms, all government-owned, also assumed the project risk. Separately and in parallel, private U.S. industry set up what became a more long-trajectory partnership with Chinese firms in support of China's aim to acquire intellectual property and know-how for design and construction of modern nuclear power plants based on the pressurized water reactor (PWR) model. In previous decades, U.S. industry already had transferred such knowhow to Japanese and European firms, and China represented an important new market. Under U.S. law, until 1998 U.S. companies were not

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[9] John Wilson Lewis, Xue Litai, *China Builds the Bomb,* Stanford University Press, 1988, p. 99

[10] Mark Hibbs, *The Future of Nuclear Power in China;* Washington, D.C.: Carnegie Endowment for International Peace, 2018, p. 64

permitted to engage in significant nuclear cooperation with Chinese entities because there was no bilateral nuclear cooperation agreement in force between the U.S. and China.

The nature of China's foreign nuclear power cooperation changed significantly after 2003-2005. Then, China's central government dramatically accelerated its plans to deploy power reactors in China, increased domestic investment to support nuclear power plant construction, and organized a competition among foreign vendors for what was widely touted would become the technology blueprint for a massive future nuclear power program in China. In 2006, China selected Westinghouse Electric Company to build an initial four nuclear power plants based on its AP-1000 design. It was widely believed that Westinghouse clinched the deal in part because it was more generous than French and Russian competitors in its offer of technology transfer to China.

During construction of the reactors, problems arose in the U.S.-China commercial relationship. By 2010, Westinghouse faced what sources in China described as a decision between trying to remain in the Chinese market for future new reactor projects, or instead focusing on providing services for future Chinese reactors. Strategic dilemmas for U.S. firms were affected by two developments: the 2011 severe accident that destroyed three nuclear power reactors in Fukushima Dai-Ichi in Japan, which led to a significant reduction in expectations for future nuclear construction in China; and China's unveiling of a new "indigenous" PWR design, the HPR-1000, representing a further iteration of technology previously developed by industry in France and the U.S. During the 2010s, advocates in the Chinese government and industry favoring the deployment of HPR-1000 would begin to challenge Westinghouse's future market prospects in China.

Westinghouse's status in China was further compounded by revelations that China's military had stolen the U.S. firm's nuclear engineering knowhow. In May, 2014 the U.S. Department of Justice (DOJ) charged a PLA officer on counts of cyber espionage; DOJ asserted that he "stole confidential proprietary technical and design specifications for pipes, pipe supports, and pipe routing within the AP-1000 plant buildings," and also purloined Westinghouse internal e-mails relating to its negotiation with its Chinese counterpart for supply of future nuclear power plants. According to DOJ, Westinghouse was one of several U.S. companies in various industries that were targeted by Chinese spies.[11] According to media reports, in 2016 the U.S. government was preparing to charge others in an investigative case that appeared to show that a Chinese nuclear firm had hired former Westinghouse personnel to steal the U.S. company's information.[12] In October 2018 the DOJ also charged that officers from Russia's GRU intelligence agency likewise had hacked into computer files at Westinghouse.[13]

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[11] https://www.justice.gov/opa/pr/us-charges-five-chinese-military-hackers-cyber-espionage-against-us-corporations-and-labor

[12] https://www.post-gazette.com/business/powersource/2017/04/05/Trump-Chinese-Westinghouse-toshiba-pittsburgh/stories/201704050137

[13] https://www.scmp.com/news/world/united-states-canada/article/2167065/us-indicts-russians-hacking-nuclear-company

By 2017 Westinghouse had in addition suffered blows from troubled nuclear power plant projects in the U.S. and filed for Chapter 11 bankruptcy protection under U.S law. The administration of President Donald Trump reportedly intervened to prevent Chinese interests from acquiring Westinghouse through third parties, after the U.S. had concluded that China might acquire "national security sensitive" technology through such a transaction.[14]

Separately, in April 2016, the DOJ charged a naturalized U.S. citizen born in China, Ho Szuhsiung, with having perpetrated espionage on behalf of the Chinese SOE CGNPC, a subsidiary of CGN, between 1997 and 2016. According to DOJ, Ho illegally sought technical information for an array of items including nuclear reactors, computer codes, and nuclear fuel technology, with the intent of using purloined information in China.[15]

After a period of forty years, the fruits of U.S investment in China's nuclear sector appear to be modest, while market prospects remain highly uncertain. China obtained considerable know-how assistance from the U.S., but cooperation in new projects has stalled since the 2010s. Most recently, a partnership between CNNC and TerraPower, a venture financed by Microsoft founder Bill Gates, to develop an advanced experimental power reactor project that many experts describe as a fast reactor, was closed down.

The U.S. was not alone during the 2010s in raising concerns about the national security implications of cooperation with China in nuclear peaceful-use activities. Several years after France and China in 2006 had agreed in principle that French industry would construct a large-scale plant to reprocess power reactor spent fuel in China, the French government conditioned the future export upon specific actions China must take concerning the siting and operation of the plant to prevent the project from assisting China's military.[16] In the United Kingdom, the government's enthusiasm during the 2010s for including CGN as a major participant in the UK's nuclear power sector has been challenged by rising concern about potential information security and geopolitical risk.[17]

In October 2018, the U.S. government announced that it had completed an internal policy review of U.S. approvals for applications for nuclear equipment and nuclear technology transfers to Chinese entities. The review established the policy to consider for approval requests related to existing and ongoing cooperation between U.S. and China regarding light-water reactors: but it also set forth that a "presumption of denial" would govern requests for transfers concerning small and medium-size/modular reactors (SMR), non-light-water advanced reactors, and any Chinese light-water reactor competing with U.S. models, including China's "indigenous" HPR-

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[14] https://www.post-gazette.com/business/powersource/2017/04/05/Trump-Chinese-Westinghouse-toshiba-pittsburgh/stories/201704050137

[15] https://www.justice.gov/opa/pr/us-nuclear-engineer-china-general-nuclear-power-company-and-energy-technology-international

[16] Mark Hibbs, *The Future of Nuclear Power in China*, p. 81.

[17] https://www.csis.org/analysis/hitachis-exit-compounds-geopolitical-complexity-uk-plan-revitalize-its-nuclear-fleet

1000 design. SMRs were included in the denial policy in part over concern that CNNC was responsible for development of PWR technology for both civilian power generation and for naval propulsion, and in the wake of discussion during the 2015 U.S. government review of the U.S.-China nuclear cooperation agreement, about whether pump technology associated with Westinghouse PWRs built in China could be diverted by China for use in naval propulsion.[18]

Three decades after U.S. nuclear power companies took aim at the Chinese market, their prospects in China appear to have considerably diminished. Future U.S. business may decline in part because China now owns the rights to use intellectual property in China for technology developed by Westinghouse, and also because China has begun deployment of its "indigenous" advanced PWR. In the wake of the Fukushima accident in Japan, China may build 200 fewer power reactors by mid-century than had been anticipated in 2005 when China's nuclear power drive began. Concern has also been raised about the risk posed by Chinese government-directed efforts to obtain proprietary know-how.

The Future of Nuclear Materials in China

China is now at a crossroads in its long-term development plan for the peaceful-use of nuclear energy that may be relevant to considerations about MCF. Beginning in the 1980s, China's nuclear R&D sector, supported by the central government, established a "three-step" development plan for nuclear power in China. Step one called for the deployment of conventional PWR-type nuclear power plants such as those in most countries including the U.S. Step two foresees the use of fast reactors including "breeder" reactors. These are to be fueled initially with the plutonium generated during operation of China's PWRs using uranium fuel and recovered through reprocessing of the spent fuel. In addition, China may use some recovered plutonium as fuel for its PWRs. China plans to make a transition from the PWR to the fast reactor from now until about mid-century. Amidst speculation that China will increase the size of its nuclear weapons arsenal, it is plausible, though not necessarily likely, that ongoing technological development of China's nuclear power enterprise might further augment China's nuclear weapons program.

Nuclear Power Materials

With a few exceptions, China's nuclear power program is based on light water reactor technology, similar to the United States. China's PWRs are all fueled with uranium dioxide (UO2). China's power reactor population currently stands at just under 50 units, and may expand to 100 or more sometime after 2030. Over time, these reactors will give rise to increasing amounts of irradiated or "spent" fuel. Today, China's spent fuel inventory is approximately 10,000 metric tons heavy metal (MTHM); depending on assumptions the discharged amount could increase by

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[18] https://www.uscc.gov/sites/default/files/8.13.08Mladineo.pdf

2050 to 110,000 MTHM.[19] (By comparison, the cumulative current spent fuel inventory in the U.S. based on operation of about 100 power reactors over a period of nearly seventy years is about 83,000 MTHM.[20]) Whereas in the U.S. spent fuel is stored and (in theory) will be disposed of in a geological repository, China has plans to reprocess the spent fuel to recover the uranium and plutonium (generated in the spent fuel during reactor operation), and use the recovered plutonium for fuel in future fast reactors. However, these plans are moving forward prudently: so far, China has separated very little of its power reactor spent fuel. Nearly all of it is stored at reactor sites.

Nuclear Weapons Materials

According to open-literature accounts, China currently is not producing nuclear material—uranium or plutonium—for use in nuclear weapons. When China embarked on nuclear weapons-making in the 1950s it pursued both uranium enrichment, using gaseous diffusion technology, and plutonium production, using reactors and reprocessing. China set up two industrial complexes, each with a so-called "production" reactor to generate plutonium in spent fuel, and a chemical reprocessing plant to separate the plutonium. The first complex, in Gansu Province, began operating in the 1960s. The second complex, in Sichuan Province, began operating in the 1970s. When the Soviet Union withdrew support for China's nuclear program in January 1960, China experienced some difficulties in operating the facilities but eventually learned how to overcome problems. Because of these difficulties, China did not utilize plutonium until its eighth nuclear weapon test, carried out in 1968, four years after China's initial test using enriched uranium. Both plutonium complexes were closed permanently in the mid-1980s.[21]

How much plutonium China produced before these facilities were closed, and how much it has used in nuclear weapons is not publicly known. According to unofficial reports, the U.S. DOD in 1999 estimated China's defense plutonium inventory as between 1.7 MT and 2.8 MT; non-official estimates reported by the Stockholm International Peace Research Institute, by the Union of Concerned Scientists, and most recently by researchers at Harvard University place the total production between 2 MT and 6 MT, 2 MT and 5 MT, and between 2.3 MT and 3.5 MT, respectively.[22]

Some observers have speculated about China's future nuclear weapons production, following a report from the US DOD in 2020 that estimated the number of nuclear weapons in China's

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[19] https://www.stimson.org/2020/spent-nuclear-fuel-china/ The inventory of spent fuel in 2016 was reported at 5,850 MTHM, with 48 power reactors in operation.

[20] https://www.energy.gov/ne/articles/5-fast-facts-about-spent-nuclear-fuel

[21] Lewis and Xue, p. 113.

[22] D. Albright, F. Berkhout, and W. Walker, *Plutonium and Highly Enriched Uranium 1996; World Inventories, Capabilities, and Policies,* Stockholm International Peace Research Institute/Oxford University Press, 1997, p. 77; Hui Zhang, *History of Plutonium Production in China,* Project on Managing the Atom, Harvard University https://www.belfercenter.org/sites/default/files/files/publication/ChinaPu-INMM2017-hzhang.pdf; David Wright and Lisbeth Gronlund, Estimating China's Production of Plutonium for Weapons, January 16, 2003 https://www.ucsusa.org/sites/default/files/2019-09/china_pu_production-revised-011603_1.pdf

current nuclear weapons arsenal as in the "low 200s" and predicting that China will double the number of its nuclear weapons without producing more nuclear material.[23]

Should in the future China decide to increase its nuclear weapons arsenal it would not need to produce additional fissile material to double the size of the arsenal. China's decision making would be relevant to a consideration of the possible status of MCF in China's defense nuclear sector, because the technology options available to China for production of nuclear weapon material are currently used or are under development to produce electricity and power reactor fuel.

<u>Existing Plutonium Inventory:</u> In principle, China could draw down its existing plutonium inventory. Assuming that Chinese weapon designs required eight kilograms per weapon (an extremely conservative estimate from the IAEA using a measure for a "threshold quantity" of elemental plutonium for one nuclear weapon), China might be able to produce an additional 200-350 nuclear weapons using its estimated plutonium inventory. A less conservative and likely more accurate estimate, based open source information about nuclear weapon design requirements, would be that China might be able to produce between 400 and 800 nuclear weapons using this material. These figures are within the bounds of open-source citations of DOD's estimate of the future size of China's nuclear arsenal, meaning that it is quite plausible that China would not in the future require production of additional fissile material for nuclear weapons and thus not seek to draw upon technologies or materials used in its civil nuclear power program.

<u>Uranium enrichment:</u> China enriched uranium to weapon-grade beginning in 1964 at a plant in Lanzhou and also at a second plant in Sichuan during the 1970s. Both plants were based on gaseous diffusion technology. China likely halted production of weapons grade uranium in 1987, roughly at the same time that China had likewise ceased operation of its dedicated reactors for plutonium production as discussed above.[24] Separately, China has set up uranium enrichment plants based on gas centrifuge technology, which provide low-enriched uranium fuel for its nuclear power reactors. I have not found any open-source literature asserting that China has resumed production of uranium for weapons. According to one non-official estimate, as of the late 1990s China may have accumulated perhaps 15-25 MT of weapon-grade uranium; according to this estimate, that amount would suffice to produce perhaps at least 500 nuclear weapons.[25] A researcher at Harvard University in 2015 reported that China is operating one centrifuge enrichment plant in Sichuan Province for "military or dual-use" purposes to enrich uranium for non-weapons applications.[26] In principle, China could use existing or future uranium enrichment capacity for production of future nuclear weapons material.

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[23] https://www.armscontrol.org/act/2020-10/news/pentagon-warns-chinese-nuclear-development

[24] Mark Hibbs and Ann Maclachlan, "China Stops Production of Military Fuel; all SWU Capacity now for Civil Use," *Nuclear Fuel*, 13 November, 1989.

[25] Albright, Berkhout, and Walker, p. 129-130.

[26] Hui Zhang, China's Uranium Enrichment Capacity: Rapid Expansion to Meet Commercial Needs, Belfer Center for Science and International Affairs, Harvard University, 2015, p. 28.

Production Reactor: China could plausibly increase its plutonium inventory by building and operating a new plutonium production reactor. China has built and operated two such reactors between the 1960s and the mid-1980s. China initially encountered difficulties in operating these facilities, but China since 1980 has accumulated considerable reactor design, construction and operating experience, and today should have no problem in constructing and then effectively operating a new reactor. Unofficial estimates would suggest that each of the two former reactors may have been rated at several hundred megawatts (thermal); A new reactor, rated at between 250 and 500 MW (thermal) might, depending on assumptions, be able to generate between 50 and 100 kilograms of weapons plutonium per year—sufficient for perhaps between 10 and 20 nuclear weapons per year. Alternatively, China could repurpose an existing Chinese research reactor to operate in a mode to favor production of weapon-grade plutonium.

Fast reactor: China could in principle construct and operate a fast reactor to "breed" plutonium, by irradiating a fertile material in the "blanket" that surrounds the core of such a reactor, giving rise to plutonium by neutron capture. Since the 1980s, China has aimed to develop future industrial-scale fast reactors for power generation. According to China's R&D blueprint for its future nuclear power development, by about 2050 China aims to design, construct, and operate a series of fast reactors with the goal of effecting a transition from the PWR to the fast reactor for power production. In principle the fast reactor would be able to "breed" more plutonium than would be consumed during routine operation, and thereby generate more nuclear fuel for an expanding fleet of fast reactors. It is also plausible that some plutonium from the fast reactor cycle could be utilized for nuclear weapons.

China's fast reactor program has benefitted from Russian assistance, particularly in the design and construction of a pilot fast reactor and a pilot reprocessing plant completed a decade ago. During the late 2000s following the establishment by the U.S. of the Global Nuclear Energy Partnership program for international nuclear cooperation, China and the U.S. initiated a technical cooperation that considered the development of fast reactor metallic fuels.[27] Currently, China is constructing two 600-MW (electric) fast reactors. In doing this, China appears to be replicating the efforts of other advanced nuclear countries, including the U.S., during the last century to establish the fast reactor on an industrial-scale and commercial basis. Challenges of cost and technology-related risk severely set back these efforts in France, Germany, Japan, the United Kingdom, and the United States. Current efforts are ongoing in India and Russia. The plan for constructing China's first industrial-scale prototype fast reactor was announced in 2005, perhaps between seven and twelve years before China likely decided to step up nuclear weapons production.[28]

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[27] Mark Hibbs, *The Future of Nuclear Power in China*, Washington, D.C.: Carnegie Endowment for International Peace, 2018, p. 47.

[28] Hibbs, p. 29-30. China's 2005 Medium- and Long-Term Plan for Development of Nuclear Energy set forth that China, after commissioning its pilot-scale fast reactor (CEFR), by 2025 would construct a prototype industrial-scale unit. The decision to begin reactor construction was preceded, and may have been delayed, by internal debates about

Implication for U.S. Interests

The subject of MCF is relevant to a consideration of China's future peaceful-use nuclear development and its implications for the United States: Nuclear technology and materials are inherently dual-use, implying that items used for peaceful applications may be used for military applications. Chinese experts trained in universities and academies may find employment in either the defense or the peaceful-use sectors. In China the boundaries between the two sectors may be fluid, including within critical organizations responsible for nuclear materials management. Whereas in the U.S. private industry companies prevail in the nuclear power sector, until now China's central government has maintained control over strategic decision making in China's nuclear program, for both energy production and weapons. The Chinese central government and the CCP will take decisions on how and when China will deploy technology to manage its growing power reactor spent fuel inventory and to attempt to affect a transition from conventional PWR technology toward fast reactor technology.

In parallel, China will take decisions about its nuclear weapon requirements. The estimates of future Chinese nuclear weapons production prompting the concern of the Committee are speculative. Should China in the future seek to double its nuclear weapons arsenal, China could achieve this without resorting to new capacity investments. In any case, China would not require technology or equipment from the U.S. or other foreign countries to produce more nuclear weapons materials, and it is unlikely that China would violate a legally-binding agreement with the U.S. to produce nuclear material that it could make by itself. [29]

China's leadership knows that international cooperation with foreign governments and industries has been essential to the success of China's nuclear power development because China had replicated the prior achievement of advanced nuclear countries including the U.S. Without the help of foreign states and industries, China's achievement would not have been possible. (This is in contrast to India, which is nuclear-armed but for three decades subject to international nuclear trade restrictions, and which despite 60 years of effort has been challenged to develop an indigenous and modern nuclear power infrastructure). Including for reasons of foreign cooperation, and because China aims to export many power reactors and other peaceful-use nuclear wares in coming years, Beijing may prefer not to take decisions about its nuclear program that would eliminate demarcations between peaceful and non-peaceful uses of technology, equipment, and materials. China would not likely elect to set back its ongoing and considerable effort to strengthen its nuclear security, including in cooperation with the U.S. Nor would China want to deprive Chinese scientists and engineers future access to educational opportunities in the U.S. and other foreign countries.

China's future bilateral nuclear cooperation with Russia, and about the power level of the reactor; some participants favored a 600-MW design and others a 1,000-MW design. During an IAEA webinar held in June 2021, a Chinese expert said that China is simultaneously building two 600-MW reactors to more quickly develop the human resources needed for the fast reactor program.

[29] https://thehill.com/blogs/congress-blog/homeland-security/239479-addressing-risk-in-chinese-nuclear-cooperation

China's nuclear cooperation with the U.S. is governed by an existing bilateral cooperation agreement. Because of the top-down role of the Chinese state over policy making and operations of nuclear energy organizations, a higher future profile for MCF in Chinese government decision making may challenge the implementation of the U.S.-China agreement beyond the policy adjustments made by DOE and NNSA in 2018. But concern in the U.S. government about China's proliferation risk is not new. Since 1985, the agreement has been amended in several areas, such as U.S. consent rights and U.S. government access to nuclear activities in China for verification; under the current agreement, some U.S. access and verification activities may still rely on informal understandings with Chinese counterparts.[30]

Greater focus on MCF may warrant lawmakers and Executive Branch agencies to further review the terms and implementation of bilateral trade understandings with China, including the nuclear cooperation agreement, specifically with regard to Chinese peaceful-use assurances and U.S. end-user verification for items exported to China, and for identification, as appropriate to U.S. industry firms, of China's technical requirements for both weapons and non-weapons applications including naval propulsion. Congress may also want to review the record of U.S.-China bilateral nuclear R&D and technology cooperation to draw lessons in the national security interest.

The inherent dual-use nature of nuclear technology and material has informed U.S. cooperation with China since the 1980s. Concerns about assisting the PLA have circumscribed US-China nuclear cooperation, but little evidence is available suggesting that the PLA has obtained any assistance from past cooperation. U.S. concerns may have succeeded in preventing US nuclear industry firms from acting in ways that would have helped the PLA. In the future, concern about the impact of MCF on U.S. nuclear commerce with China may be less than for some other U.S. industry sectors, particularly those where there is less awareness about the challenges of controlling dual-use items.

How significant a challenge MCF in China will present to the United States in the nuclear power area will depend to a considerable extent on how deeply engaged the U.S. nuclear industry will be in China's future nuclear power program. On that basis the threat to U.S. industry may decline. The aspirations of U.S. industry, articulated by its industry representatives including to the U.S. Congress and to the Executive Branch during the 1990s and 2000s, will not likely be

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[30] In June, 1985, for example, the Arms Control and Disarmament Agency informed Congress that, following a review, "a favorable net assessment of the adequacy of the provisions of the proposed agreement to ensure that any assistance furnished thereunder will not be used to further any military or nuclear explosive purpose." https://fas.org/sgp/crs/row/RL33192.pdf According to U.S. export control personnel, one area where the U.S. relied on informal understandings with China, at least prior to 2015, concerned U.S. verification of declared end users of U.S. nuclear dual-use exports to China.

attained. U.S. firms told Congress in 1997, for example, that the future Chinese nuclear power market might be worth $50 billion to U.S. companies.[31] Looking toward the 2015 renewal of the U.S.-China agreement, in December 2014 China announced that it would be spending $11.2 billion per year on new nuclear power plant construction for the next ten years.[32] When Westinghouse was awarded contracts for four nuclear power plants in China in 2007, industry representatives asserted that more than 30 more such plants were "planned."[33] Today that future does not look so bright. In the wake of the Fukushima accident, and China's efforts to deploy "indigenous" technology for nuclear power generation, U.S. nuclear power plant equipment vendors may shift their sights away from a China market that looks increasingly risk-laden and toward efforts to launch nuclear power projects elsewhere including in the U.S., depending on government support. For the U.S. nuclear industry, the political risk deriving from U.S.-China relations, and the project risk component associated with aggressive Chinese business practices, may increase the overall risk profile for doing business in China.

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[31] https://fas.org/sgp/crs/row/RL33192.pdf p. 20
[32] https://fas.org/sgp/crs/row/RL33192.pdf p. 11
[33] https://fas.org/sgp/crs/row/RL33192.pdf p. 3